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SEPTEMBER 2014

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This 4.3° F.o.V. image of Eta Carina (NGC3372) was imaged by Wolfgang Promper using the Tele Vue-NP127fli & FLI Proline 16803 camera.

SKY & TELESCOPE

September 2014 VOL. 128, NO. 3

On the cover: NASA's next Mars mission will help astronomers discover how the planet lost its atmosphere.

IMAGE: LOCKHEED MARTIN

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S&T TEST REPORT

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Robert Naeye
Spectrum

Inflation & Our Deep-Sky E-book

WHEN THE BICEP2 TEAM announced this March that it had found a specific polarization pattern in the cosmic microwave background (CMB) that was predicted by inflation, I felt a surge of elation. Finally, after all these years, the idea that the early universe experienced an exponential growth spurt seemed confirmed, and I felt satisfaction in science's ability to predict yet another phenomenon before it was discovered.

But in the back of my mind, I knew that the BICEP2 result was by no means a done deal. As I told friends and family the day of the announcement, I wouldn't fully buy into it until other teams observed the same signal. And I felt a tinge of suspicion that the signal turned out to be easier to detect than many cosmologists expected. When Alan MacRobert wrote his July issue cover story, he made sure to include the caveat ". . .if the other teams now racing to confirm the find succeed. . ."

As of this writing in early June, the BICEP2 detection has been called into question. As Camille Carlisle explains on page 12, it's possible that foreground dust is primarily responsible for the polarization pattern attributed to inflation. It's too early to say if the BICEP2 result will stand, but if not, it will be yet another example of the self-correcting nature of science. The general public might not perceive it that way, but this is an attribute of science. How many other intellectual disciplines have such a clearly established methodology for purging themselves of wrongful ideas?

A retraction would be a deep disappointment for inflation advocates, but the theory itself would remain on solid ground. It's still consistent with all other astronomical observations, such as the statistical pattern of temperature variations in the CMB, and the theory itself is well-motivated. It's quite possible that the polarization signal from inflation is weak and extremely difficult to distinguish from all the foreground sources.

On a different note, I want to tell you about our terrific new e-book titled *Summer Deep Sky Observing Projects*. Alan MacRobert assembled 15 of our best articles from recent years about deep-sky observing. This convenient e-book gives you many dozens of telescopic targets, telling you how to find them and what you can expect to see. If you're planning to take your telescope outside on clear summer evenings, check it out at **www.shopatsky.com/summerskyobserving**. ✦

Robert Naeye
Editor in Chief

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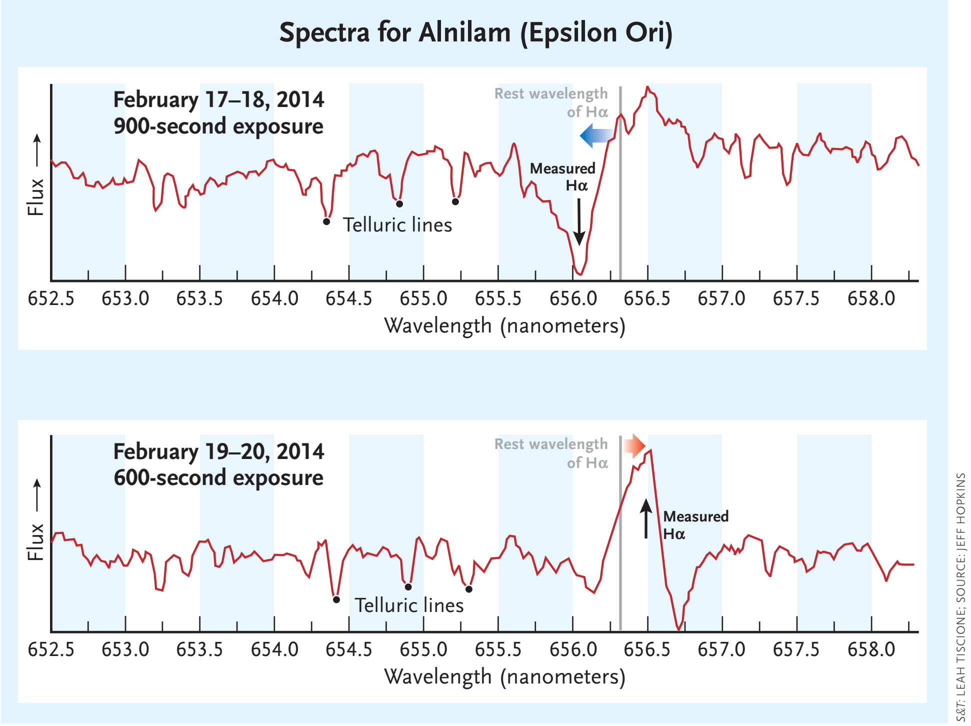
Call for Orion Observers

After a very successful Epsilon Aurigae campaign (*S&T*: Mar. 2012, p. 18), I have started another astronomical endeavor called the Orion Project. Initially it began as a spectroscopic program for Betelgeuse but has expanded to Rigel, Mintaka, Alnilam, and Alnitak. Edward Guinan (Villanova University) and John Martin (University of Illinois, Springfield) have been watching Betelgeuse for years, and with their encouragement I'm coordinating an ongoing spectroscopic and photometric campaign to amass continuous observational data for these stars.

Even if you are not experienced or are just getting into photometry or spectroscopy, this is a good project to learn from. The constellation Orion is unique in that it is easily visible from much of the populated world. It's also visible during the fall and spring seasons, making observing pleasant. Because the stars are bright, they're ideal for spectroscopy, even with modest telescopes. Photometry presents just the opposite challenge, because CCD photometry requires special bright-star techniques. The SSP-3 and SSP-4 PIN diode photometers are ideal for this work, because their decreased sensitivity works well for the bright stars.

We have several observers from around the world doing both photometry and spectroscopy on the project's five stars. One interesting thing we've found is a repeating switch in Alnilam's spectra, with the hydrogen-alpha line flipping from absorption to emission on the order of hours to a couple of days. This shift also appears in professional observations. It might be due to variability in the stellar wind emission.



The central star in Orion's Belt, Alnilam, has a hydrogen-alpha feature that flip-flops between being an absorption and an emission line. Amateur Jeff Hopkins took these spectra with a Meade 12-inch LX200GPS Schmidt-Cassegrain and Lhires III 2400 spectrograph.

Interested observers will need the proper equipment and knowhow. Help and mentoring are available. If you're interested, please visit the project website at **www.hposoft.com/Orion/Orion.html** or e-mail me at **phxjeff@hposoft.com**.

Jeff Hopkins
Phoenix, Arizona

Simply Wonderful

James Mullaney makes some valid points in his article about observing with small scopes (*S&T*: Apr. 2014, p. 38). A small instrument has its place in any observer's arsenal. Those wanting to fill the gap between small binoculars and larger telescopes could instead consider a pair of big binoculars. A pair of 25×100 binoculars provides more light grasp than Mullaney's 90-mm spotting scope, as well as a larger field of view (2.3° versus 1.7°). This view allows for terrific "big-picture" observing, allowing you to see star clusters and nebulae in large, rich fields of background stars. Big binoculars also greatly enhance the sense of depth perception that Mullaney speaks about because the observer is using both eyes, and most observers will find better contrast in the image.

Many 80- to 125-mm binoculars can be purchased at a nominal price. Well-mounted on a good tripod, big binoculars are quick to set up for a viewing session. I've spent the last year rediscovering the Messier objects and observing obscure, large star clusters that I can see only poorly in large reflectors. One class of object that Mullaney failed to mention is dark nebulae; dozens of these objects are beautifully seen in rich Milky Way fields with 25×100 binoculars.

Mark Bratton
Limerick, Saskatchewan

Thank you for Mullaney's "Stargazing Simplified." He reminded many of us of why we became amateur astronomers in the first place: to enjoy the spiritual beauty of the sky.

I can trace my interest back to when I first saw Sputnik 1 fly overhead on a brilliant October night in 1957. These days, my most convenient instrument for casual observing is a pair of 20×80 binoculars

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and a lawn chair.

Some years ago Walter Scott Houston wrote in his Deep-Sky Wonders column that some of his most enjoyable observing was naked-eye: "I always feel good when I look at the stars," he wrote. I agree: an hour or so of plain stargazing helps put your life in proportion.

Greg Thorup
Cumberland, Maine

Thank you for publishing Jim Mullaney's article! Probably half the members of my astronomy club pursue the hobby as Mullaney describes it. One of our club officers even prefers to describe herself as "a stargazer" instead of an "amateur astronomer," because even though she has enormous high-tech ability, she often chooses binoculars or the simplest telescope to view, appreciate, and contemplate the beauty and mystery of the night sky. Mullaney's article is courageous in a world of gadget-driven amateur astronomy.

Donald Weitzman
Los Angeles, California

Moving Mars?

The news article "Mixed Message for Rock Makeup" by Emily Poore (*S&T*: May 2014, p. 12) suggests that the mixed composition of the asteroid belt resulted from the orbital movement of Jupiter and that the planet at one point came perhaps as close to the Sun as the present orbit of Mars. So where did Mars go?

Orbital shifts of the outer planets have been also implicated in the origin of the Late Heavy Bombardment, for example, but similar orbit changes of the inner planets are rarely, if ever, discussed. If the Earth were slightly closer to a less luminous early Sun, wouldn't this help ease the constraints in explaining the faint young Sun paradox?

Greg Konesky
Via e-mail

Editor's Note: *In the Grand Tack model, Mars hadn't fully formed when Jupiter and Saturn forayed inward. During this time there was only a rocky planetesimal disk. The inward movement of Jupiter and Saturn truncated this rocky disk (causing it to shrink from 1.5 astronomical units to 1 a.u.). It's possible that Mars began forming around 1 a.u. and then moved out due to the gravitational perturbations before it could beef up to the size of Venus and Earth. A moving Mars might also have helped scatter iron-rich planetesimals into the inner asteroid belt, where they're commonly found today.*

As to the faint young Sun paradox, that arises about 3½ to 4 billion years ago, after the period on which the Grand Tack and related models focus. We have not heard of expectations that the planets were migrating substantially at this point. One recent explanation for the paradox is that the composition of early Earth's atmosphere would have allowed life to arise, even with the faint Sun (S&T: Oct. 2013, p. 11).

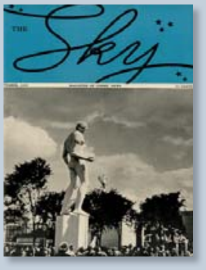
For the Record

✷ *June 2014, p. 47: The caption for Alpha Librae should identify the F4 star as the secondary, not primary.*

You can find all errata for our 2014 issues at **skypub.com/errata**.

75, 50 & 25 Years Ago

Roger W. Sinnott



September 1939

Lost Meteorite "In 1859, Dr. John Evans, government geologist for Washington and Oregon, was exploring the southern coastal region of the latter state. . . . He said [of the meteorite he found], that 'the mass, about three feet of which is above ground, is in the mountains, about 40 miles from Port Orford on the Pacific and easily accessible by mules. . . . '

"Many eastern scientists have in recent years searched for this valuable object. In 1932, Dr. H. H. Nininger, president of the Society for Research on Meteorites, looked over the territory without success. But he remarks, 'I think there is no doubt that the meteorite is somewhere around there.'"

Samples of the chunk that Evans harvested were sent to the Vienna Academy of Science and the Smithsonian Institution. But Evans died in 1860 and the Port Orford meteorite has never been found. Some now suspect it was a hoax.

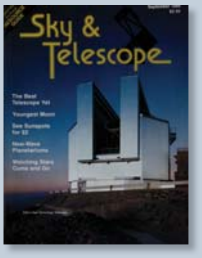
September 1964

Why the X-rays? "Can neutron stars be the sources of the intense X-rays discovered last year in Scorpius and Taurus? . . . The hypothesis seemed attractive for the Taurus source . . . for it is centered on the Crab nebula, the remnant of a supernova explosion in A.D. 1054. It had been suggested that such outbursts produce neutron stars.

"To test the neutron star conjecture for the Taurus source, Naval Research Laboratory scientists sent a rocket-borne X-ray detector aloft from White Sands, New Mexico, on July 5th. It attained an altitude of 144 miles at the right time and place to observe an occultation of the Crab nebula by the moon.

"A point source such as a neutron star would have disappeared abruptly when the moon's edge reached it. Instead, the X-ray intensity diminished gradually during the five minutes of measurement."

The X-rays actually arise in the hot gas of the nebula surrounding the Crab pulsar, a rapidly spinning neutron star detected in 1968. As the pulsar gradually spins down, it dumps the lost rotational energy into the gas and powers the X-rays.



September 1989

Outspoken Astronomer "The Chinese astrophysicist Fang Lizhi has become China's best-known dissident. Fang is a theoretical cosmologist who has recently been working on the topology of the universe. . . . Fang was not directly involved in the Chinese student uprising last spring. But after the government cracked down on the movement [at Tiananmen Square], it singled out Fang as a prime instigator. He took refuge in the American embassy . . . with his wife Li Shuxian, who is herself a physicist, and their son."

Allowed to leave China a year later, Fang settled at the University of Arizona and studied the early universe, galaxy clusters, and the interstellar medium. He passed away in 2012.

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COSMOLOGY | Inflation Evidence Inconclusive

Two new analyses suggest that observations heralded as evidence for the universe's brief growth spurt (*S&T*: June 2014, p. 10) don't show what researchers thought they did.

In March, BICEP2 team members announced that they'd detected swirling polarization patterns called B-modes in the cosmic microwave background (CMB), the afterglow from the universe's birth. These patterns should exist in the CMB if the universe underwent a moment of exponential expansion called inflation that lasted roughly a nano-nano-nano-nanosecond.

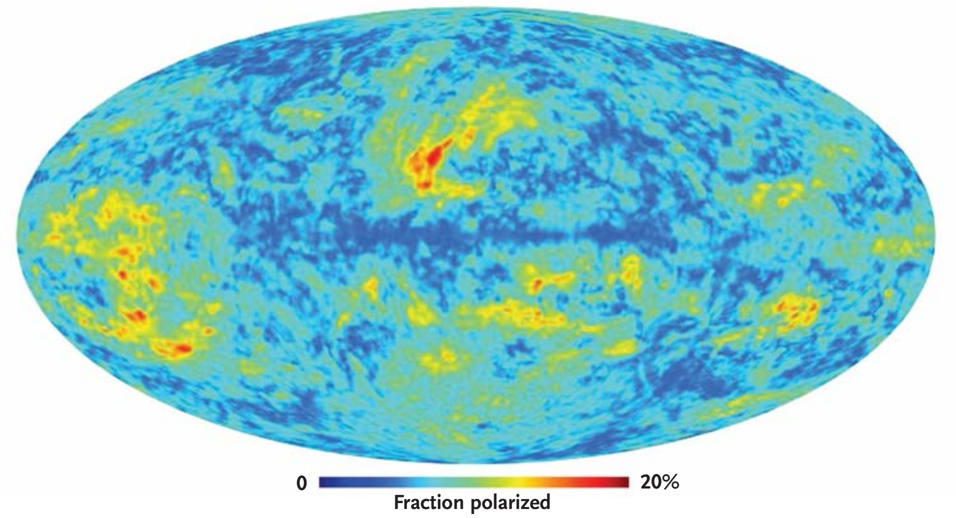
But now, a team from the University of California, Berkeley, and another team from Princeton and New York University are painting a different picture. The teams combined the BICEP2 data with a new map of the polarized dust in the Milky Way, created from observations by ESA's Planck satellite. Using these data, both teams say they can't distinguish whether the B-modes detected by BICEP2 are in the CMB or in the emission from dust filling our galaxy.

The problem is twofold. One, cosmologists observe from inside our galaxy. Looking at the cosmos from inside the Milky Way is like looking at a road through a fogged, bug-spattered windshield. Observers must peel away these foreground signals so that they can see the CMB.

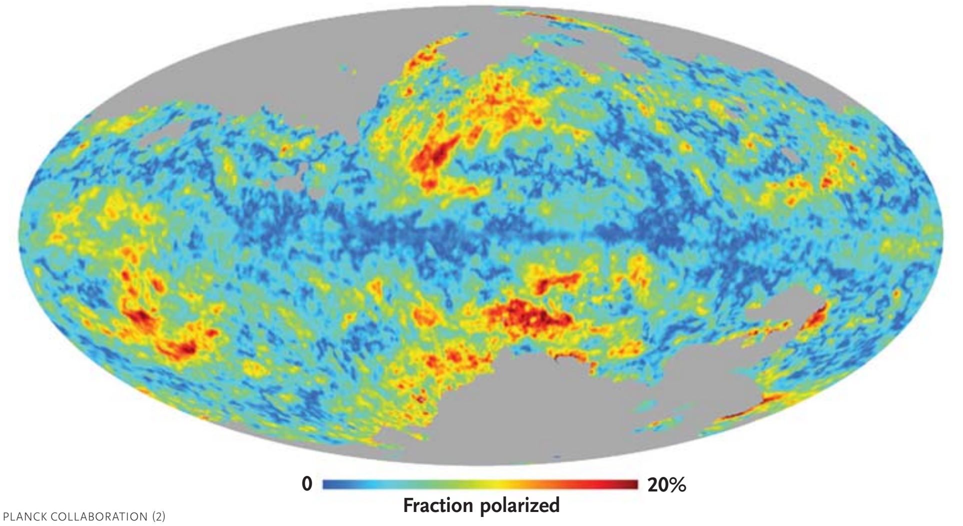
At the frequency BICEP2 observed, the three main signals are the CMB (which is polarized at a level we're trying to figure out), dust in the Milky Way (also polarized), and the cosmic infrared background (CIB, unpolarized). The CIB is the sum of infrared light from billions of unresolved, dusty galaxies, and it suffuses the cosmos much as the CMB does.

To tease out the CMB, cosmologists must identify how much of the signal they observe from a given part of the sky comes from each source. The BICEP2 team used a preliminary all-sky map of polarized dust emission, taken from a Planck team member's conference presentation in April 2013.

But this map *included* the CIB — a major problem, because the CIB is integrated light from dust in a whole bunch of other galaxies. The CIB looks like emission from our galaxy's dust, except it's unpolarized. When researchers sum all the dusty emission together, it looks about 5% polarized. But remove the part that's unpolarized, and the *fractional polarization* of what's left goes up, to an average of roughly 10%.



This preliminary map of polarized emission from the ESA's Planck satellite includes the cosmic infrared background, which damped the polarized signal from dust in the Milky Way.



PLANCK COLLABORATION (2)

Once the Planck team subtracted the cosmic infrared background, the signal from polarized dust in our galaxy became stronger. This signal might be the one that BICEP2 detected.

The Planck team knew the CIB was a problem and spent a year weeding it out. They released a preliminary, CIB-less dust map in May. Using this revised map, the two new studies say the BICEP2 team might have lowballed the amount of polarization in their observations that comes from Milky Way dust.

In other words, scientists can't conclude anything about where these B-modes come from.

Frequency Matters

However, here's the #2 of the twofold problem: all the teams are extrapolating.

The Planck polarization map is at 353 gigahertz (GHz), where the dust emission is strong. But BICEP2 observed at 150 GHz. So cosmologists must (1) know how much of the galactic dust emission is polarized at 353 GHz; (2) correctly deduce what the signal looks like at 150 GHz, where the dust emission is weaker; and (3) correctly split that polarization signal into its two types, E-modes and B-modes.

The BICEP2 team extrapolated to 150 GHz using a 353-GHz, CIB-tainted map of the section of sky that it observed. The two other teams extrapolated using a 353-GHz map that's clean of the CIB but *doesn't include* the BICEP2 field of view. The Planck team has yet to release its data for regions near the north and south galactic poles because those sectors are incredibly difficult to analyze. And BICEP2 observed near the south galactic pole.

The Planck analysis is difficult because the mission's team is working on a cosmic scale. The satellite observed the CMB to high precision in order to measure the parameters that characterize the universe (*S&T*: June 2013, p. 10). The team has to correlate all its calculations with one another to make sure the resulting cosmology is self-consistent — they can't have one result that doesn't jibe with another. Until that's done, they're not done.

The final Planck data will obviate the need to extrapolate. Planck measured polarization at 30, 44, 70, 100, 143, 217, and 353 GHz. In the units that the cosmologists use to make their maps, the CMB signal's strength doesn't change as you look in different frequencies. But the dust signal does. So if researchers can see how the signal changes as they move between frequencies, they can effectively wipe the dust off their cosmic windshield.

The Planck team will release the temperature and polarization data from the full mission in late 2014 (no later than the first week of December, and maybe sooner). The previous release in 2013 included only the first half of the temperature data. It's too soon to say whether the upcoming release will include Planck's version of direct B-mode measurements.

■ **CAMILLE M. CARLISLE**

Read the teams' research papers at skypub.com/dustybmodes.

EXOPLANETS | Ancient Kapteyn's Worlds

Astronomers have discovered two exoplanets orbiting Kapteyn's Star, a nearby, dim *M* dwarf in a Milky Way Galaxy halo orbit that likely formed in another galaxy.

Kapteyn b and c might be super-Earths, with minimum masses of 4.8 and 7 times Earth's, respectively. Kapteyn b goes around its host star in 48 days, closer than Mercury's orbit around the Sun. Because the star is a cool red dwarf, the planet lies in its habitable zone.

At 8 arcseconds per year, Kapteyn's Star moves across the sky at a fast clip, covering the diameter of a full Moon every 225 years. Only Barnard's Star migrates more quickly.

Astronomers explain this speed with a dwarf-galaxy origin. If the Milky Way tidally shredded a dwarf galaxy, that interaction would have flung the dwarf's stars into different orbits. Currently, Kapteyn's Star is only 12.7 light-years away; it could be the remnant of a tidally stripped galaxy whose surviving core might be the globular cluster Omega Centauri.

The interaction happened at least 10 billion years ago, meaning that Kapteyn's Star and its planets are roughly twice as old as the solar system, Guillem Anglada-Escudé (Queen Mary University of London and University of Göttingen, Germany) and colleagues report in an upcoming *Monthly Notices of the Royal Astronomical Society*. That makes it one of the most ancient planetary systems known.

But because *M* dwarfs emit harsh radiation in their early years, Kapteyn b might not actually be habitable, suggests a study by Ofer Cohen (Harvard-Smithsonian Center for Astrophysics) and colleagues. Harsh stellar weather would strip the atmosphere of a rocky planet orbiting in a red dwarf's habitable zone, leaving the planet more Mars-like than Earth-like, Cohen's team announced June 2nd at the American Astronomical Society meeting in Boston.

■ **SHANNON HALL**

SPACECRAFT
ISEE 3 Phones Home

NASA's 35-year-old International Sun-Earth Explorer 3 spacecraft is back in action. In late May, about 20 space buffs banded together to revive ISEE 3.

Launched in 1978, the craft studied the solar wind and completed two successful comet flybys. It's been silently cruising around the Sun since 1999. But ground controllers neglected to turn off its carrier signal.

Realizing that ISEE 3 would pass close to Earth in August 2014, volunteers banded together to reestablish communication. NASA no longer had radio dishes rigged to transmit and receive at the right frequency, nor the programs needed to command the craft — nor the time or money to hunt it down.

Led by veteran spacewatchers Dennis Wingo and Keith Cowing and collectively known as the ISEE-3 Reboot Project, the group spent months unearthing the old code, scavenging equipment, and finding two suitable radio dishes. A crowdfunding effort yielded more than 2,200 donors and nearly $160,000.

First contact came on May 29th, hours after NASA managers gave the go-ahead for the attempt. Using a makeshift receiver and transmitter installed at the Arecibo radio observatory in Puerto Rico, the team successfully established a two-way radio link at a transmission rate of 512 bits per second.

Normally, ISEE 3's 355-day-long orbit around the Sun would have taken it sailing by Earth in August. But with the craft back under human control, project members plan to fire its rocket to direct it into a holding pattern near the first Lagrangian point, roughly 1.5 million kilometers (0.9 million miles) from Earth's sunward side.

Although it carries no cameras, ISEE 3 has two working radio systems, ample fuel reserves, and a dozen instruments for studying charged particles, electromagnetic fields, and related phenomena.

■ **J. KELLY BEATTY**

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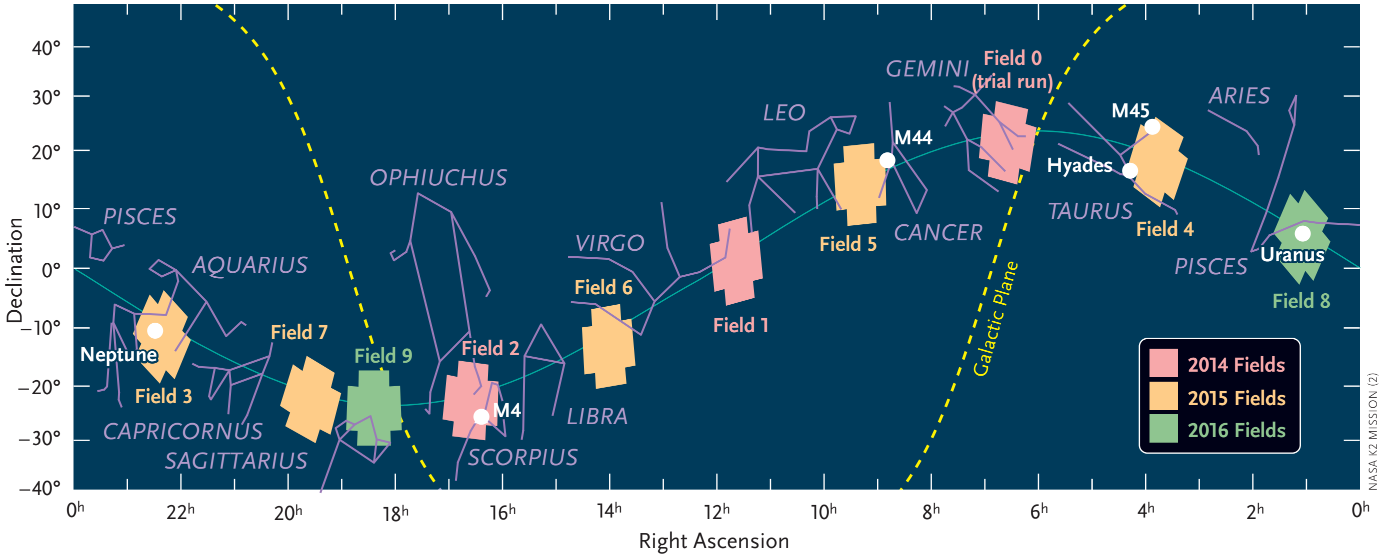


MISSIONS | Kepler Spacecraft Starts New Mission

NASA's crippled planet-hunting spacecraft is back in business and commissioned for at least two years of productive new science.

When the second of four reaction wheels seized up in May 2013 (*S&T*: Aug. 2013, p. 10), the Kepler spacecraft's observing days seemed over. To observe with its hallmark accuracy, the spacecraft must control its position in three dimensions, which normally requires three gyroscopes.

However, scientists and engineers quickly came up with a Plan B: combine solar radiation pressure and the two functioning reaction wheels to stabilize the spacecraft's pointing.

In May, NASA approved the new mission, dubbed K2. K2 is a community-driven mission, with targets taken solely from astronomers' proposals. It will take advantage of the spacecraft's changing field of view, which not only must stay confined to the ecliptic plane (due to the reliance on sunlight's feeble pressure) but also must migrate around the sky as it orbits the Sun (see the diagram above).

Kepler's new attitude expands the range of its scientific research. Over the next two years, the spacecraft will watch nine fields of view, including populous star fields in the Milky Way and active galactic nuclei. Each campaign will last approximately 80 days, with four to five campaigns fitting into each 372-day orbit around the Sun.

Campaign 1 lasted from May 30th until August 1st and focused on the North Galactic Cap. Subsequent campaigns will examine notable near-ecliptic star clusters, such as the Pleiades (M45) and the Hyades (Campaign 4) and the Beehive Cluster (M44) and M67 in Cancer (Campaign 5). Mission planners are still requesting input for targets for the final four campaigns, so the exact coordinates for future campaigns are not yet set in stone.

"If you don't propose it, we don't do it," said Martin Still (NASA Ames Research Center) on June 3rd at the American Astronomical Society meeting in Boston. "There are no guaranteed targets."

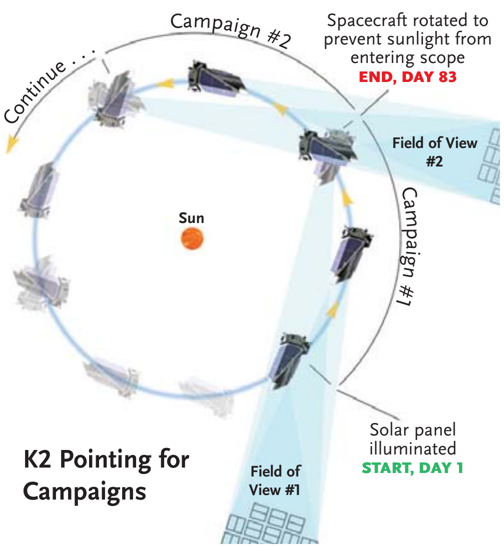
NASA has allocated $4 million for K2 guest observers over the next two years. All data will be freely accessible through the Mikulski Archive for Space Telescopes and the NASA Exoplanet Archive.

Not everything is smooth sailing for the new mission. The fact that the spacecraft observes near the ecliptic means that bright solar system objects will occasionally move across the field — Mars passes right through Campaigns 2 and 3, for example. The glare and reflections can degrade the data. Additionally, the noise level in K2's photometry is 1½ to 2 times stronger than in the original mission.

The aim point also drifts slightly, so mission planners must fire the spacecraft's thrusters every 6 hours to compensate. This "roll and reset" method will affect the photometry, said Tom Barclay (NASA Ames Research Center), but this can be accounted for in the data analysis.

■ **MARIA TEMMING**

Above: **The Kepler spacecraft will observe nine campaign fields over the next two years, following the ecliptic plane due to its mechanical limp.**



K2 Pointing for Campaigns

Read more about NASA's new K2 mission at skypub.com/k2works.

LUNAR | New Moon Results Explore Lunar Origin, History

Three new results are bringing planetary scientists closer to understanding how Earth's natural satellite was born and why it looks the way it does.

The Moon likely formed when a Mars-size object (often called Theia) struck the young Earth. This glancing blow ejected a huge jet of debris that formed a ring around our young planet and rapidly coalesced into the Moon.

Until recently, the best answer for when this big splat occurred was roughly 4.47 billion years ago. However, in June Guillaume Avice and Bernard Marty (University of Lorraine, France) presented an earlier date at the Goldschmidt Geochemistry Conference. Their analysis of xenon trapped inside quartz-bearing rocks from South Africa and Australia allows them to estimate how much xenon early Earth lost to space (during, say, a major impact). The team's analysis suggests the Moon formed 4.53 billion years ago, just 40 million years after the solar system did.

If the giant-impact hypothesis is correct, the Moon should be a mélange of proto-Earth and Theia. Yet previous analyses have failed to find a distinction between the ratios of oxygen's three isotopes in terrestrial and lunar rocks.

In *Science* for June 6th, Daniel Herwartz (University of Göttingen and University of Cologne, Germany) and colleagues report detecting that long-sought difference. The team used improved techniques to derive the isotopic ratios of oxygen-16, -17, and -18 and found a difference of 12 ± 3 parts per million in the ^{17}O:^{16}O ratios. This result puts strict limits on Theia's composition.

The third lunar result offers a possible solution to the age-old question of what put the Man in the Moon. Various researchers have tried to explain why dark maria cover the lunar nearside but cratered highlands cover the farside.

Writing in the June 20th issue of *Astrophysical Journal Letters*, Penn State researchers Arpita Roy, Jason Wright, and Steinn Sigurðsson think they have the answer. When the Moon first formed it was much closer, just 5% to 10% of its present distance, and its rotation quickly became tidally locked. Both bodies were still hot from the collision, with Earth's surface a red-hot 2500°C (4500°F). This meant the lunar nearside was continually seared by the glowing Earth that dominated its sky, making it too hot for any lunar minerals to condense.

But the farside, out of sight from Earth, cooled much faster. The first solids to form on the Moon were therefore more likely to condense there, building up a crust with minerals rich in aluminum and calcium.

Later on, titanic collisions battered the young Moon. The nearside's relatively thin crust, fractured deeply by the largest impacts, provided an easy conduit for dense, metal-enriched magmas to rise to the surface. These formed the pattern of dark maria seen today. But due to the farside's thicker crust, similar eruptions were almost nonexistent.

■ **J. KELLY BEATTY**

IN BRIEF

New Meteor Shower Disappoints. Some dynamicists had predicted that Comet 209P/LINEAR would create an active meteor display in the early morning of May 24th (*S&T*: May 2014, p. 30). But reports compiled by the International Meteor Organization suggest that the Camelopardalids hit a maximum zenithal hourly rate of 20. The low rate was in part because the particles moved slowly for meteoroids (about 20 km/sec, or 45,000 mph), making them dim. The poor display might also be because this year's shower involved comet particles shed more than a century ago and not the most recent or densest debris strands. A full analysis is at skypub.com/camels2014.
■ **J. KELLY BEATTY**

Active Galaxies Actually Different. The zoo-like variety of active galaxies might be due to evolution, argue two teams in the *Astrophysical Journal* and *Nature Physics*. Every active galaxy contains a gorging supermassive black hole at its core. Astronomers think complex structures including a dusty torus encircle the black hole, obscuring it from view from some angles. Until now they thought the different types of active galaxies they observe are merely the same structures seen at different angles. But the new studies show that obscured active galaxies behave differently than their exposed counterparts: they cluster closer together and tend to reside near gas-rich, star-forming galaxies. The results suggest that the structures surrounding supermassive black holes are not universal but instead evolve over time.
■ **MONICA YOUNG**

Star Cluster Runs Away. One of the several thousand globular clusters orbiting the elliptical galaxy M87 appears to be screaming toward us at 1,025 km/sec. The cluster, dubbed HVGC-1 (for *hypervelocity globular cluster*), is going fast enough to escape the entire Virgo Cluster in which M87 resides, Nelson Caldwell (Harvard-Smithsonian Center for Astrophysics) and colleagues report in the May 20th *Astrophysical Journal Letters*. The team suggests that, if a double supermassive black hole lurks in the galaxy's core, a three-body interaction with the cluster could have slingshotted HVGC-1 out. There's circumstantial evidence that M87 might have a double black hole, but for now astronomers don't know how the galaxy ejected the cluster.
■ **MONICA YOUNG**

First Direct Exoplanet Spin Measurement. Ignas Snellen (Leiden Observatory, The Netherlands) and colleagues have used infrared observations to clock the spin of the young exoplanet Beta Pictoris b, the team reports in the May 1st *Nature*. The planet's mass is roughly 11 times that of Jupiter and rotates at 25 km/sec, much faster than Jupiter (13.3 km/sec) and Earth (0.5 km/sec). This spin seems to uphold the correlation seen in the solar system between spin and mass, with more massive planets rotating more quickly. ✦
■ **SHANNON HALL**

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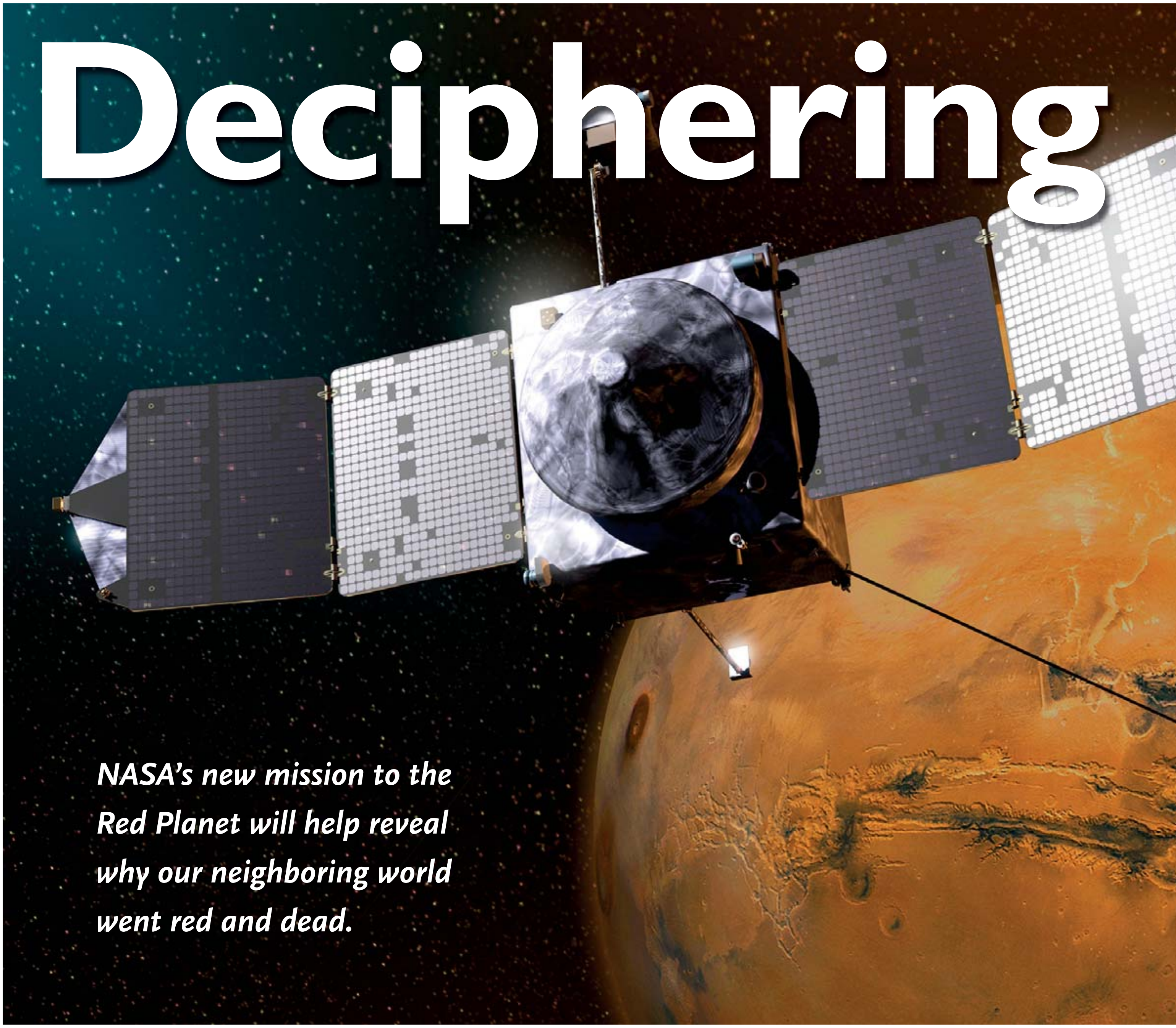
Deciphering

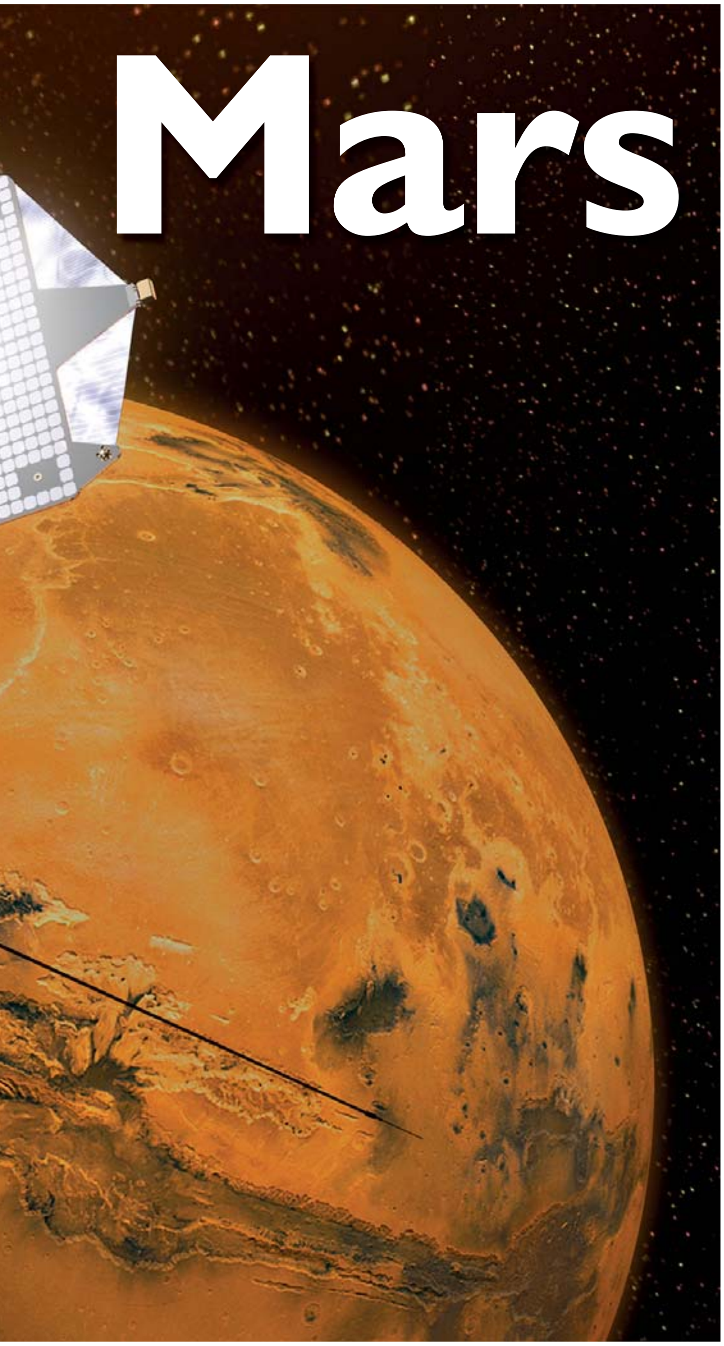


NASA's new mission to the Red Planet will help reveal why our neighboring world went red and dead.

CAMILLE M. CARLISLE

H. G. Wells's time machine has nothing on NASA's latest Mars mission. The Mars Atmosphere and Volatile Evolution Mission (MAVEN) is a flying laboratory, a nimble orbiter that will reach its target planet this September. But don't be fooled by its 2014 arrival: its team intends to travel back in time and uncover what happened in the Red Planet's ancient past.

This spacecraft is the first dedicated to directly sampling Mars's upper atmosphere from orbit. Unlike previous Mars missions, MAVEN doesn't carry a visible-light camera. But this batlike craft will give astronomers an unrivaled look at Mars's current atmosphere and how the planet has been losing its atmosphere over time. These atmospheric data should in turn help answer the two questions that mystify anyone who looks at the long-gone waterways on this bleak, frigid world: was ancient Mars ever habitable, and if so, what went wrong?



NASA / GSFC

The Ancient Atmosphere

Planetary scientists know that ancient Mars looked totally different than today's Mars. The oldest craters have had their edges worn down by precipitation, and gully and delta features suggest liquid water once flowed, albeit perhaps intermittently (*S&T*: Sept. 2013, p. 16).

Liquid surface water would require higher temperatures and a much higher atmospheric pressure — maybe between 50 and 200 times the current pressure — than those on Mars now. These days, the planet's air pressure is less than 1% of that at sea level on Earth, equivalent to being in our stratosphere.

Chemical evidence also indicates that Mars's atmosphere has mostly disappeared. Elements exist as different isotopes, distinguished by the number of neutrons in their nuclei. One example is hydrogen (1 proton) and its heavier and much less common form, deuterium (1 proton and 1 neutron). An element's isotopes exist in specific ratios with respect to one another. So when the ratio of two isotopes in a sample unnaturally favors the heavier, less common one, scientists can use the ratio to estimate how much of the more common one must have been lost in order to produce the levels they detect.

Isotopic studies of Mars's atmosphere for several elements, including hydrogen, argon, and carbon, suggest that the planet has lost between 25% and 90% of its original atmosphere — with the data leaning toward the higher end of that range (see the table below).

There are two directions an atmosphere can go when it disappears: up or down. But as far as down goes, scientists haven't found a place where all the missing gas could hide. The two most common compounds outgassed by rocky planets as they grow their atmospheres are water (H_2O) and carbon dioxide (CO_2), and these must have existed in large quantities on early Mars. In the presence of liquid water, the carbon dioxide would have dissolved, reacting with rocks to form carbon-bearing minerals called carbonates. That's what happened on Earth, and

The MAVEN orbiter arrives at Mars in September to investigate which processes drive the loss of the planet's atmosphere.

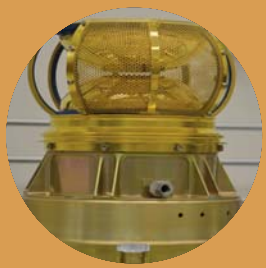
Martian Isotopic Ratios & Atmospheric Loss

Isotopic Ratio	Measured Value (Relative to Earth's)	Amount Lost (%)
deuterium/hydrogen	5	60–75
argon-38/argon-36	1.3	50–90
carbon-13/carbon-12	1.05–1.07	50–90
nitrogen-15/nitrogen-14	1.7	90
oxygen-18/oxygen-16	1.025	25–50

Chemical isotopes — such as hydrogen and its heavier form, deuterium — exist in specific ratios with one another. When these ratios are skewed in favor of the less common form, the change can tell scientists how much of the other isotope was lost. In this table, the number attached to the element name is the total number of protons and neutrons in the atom's nucleus.

MAVEN's Science Instruments

Remote Sensing Package	**IUVS** Imaging Ultraviolet Spectrometer
Mass Spectrometry Instrument	**NGIMS** Neutral Gas & Ion Mass Spectrometer
Particles & Fields Package	**SEP** Solar Energetic Particles **STATIC** SupraThermal & Thermal Ion Composition **SWEA** Solar Wind Electron Analyzer **SWIA** Solar Wind Ion Analyzer **LPW** Langmuir Probe & Waves **MAG** Magnetometer



Solar Wind Electron Analyzer

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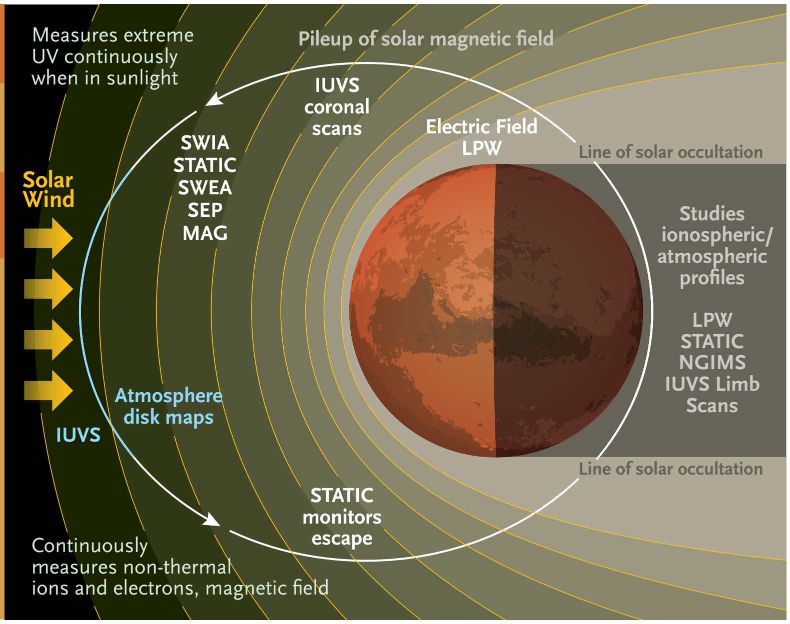


S&T: LEAH TISCIONE, SOURCE: MAVEN TEAM

NASA / KIM SHIFLETT

Above: **The MAVEN spacecraft will follow an elongated orbit around Mars, dipping down to 150 km (in some places 125 km) above the surface at its closest and flying 6,000 km above at its farthest. The orbit precesses in both latitude and local solar time so that scientists can study as much of near-Mars space as possible. Shown are the investigations and pertinent instruments involved for various parts of the spacecraft's orbit.**

Left: **Technicians pack up the MAVEN orbiter in its launch cone. Once wrapped up, the complete package sat on top of an Atlas V rocket for launch (see page 26).**

planetary scientists expected to find widespread carbonate deposits on Mars. But they haven't.

Plus, although Mars possesses vast water-ice deposits beneath its surface, deuterium levels suggest that the planet has lost roughly 70% of its water.

If the atmosphere isn't hiding underground, then some of it must have been lost to space. Gas can escape if it's hot enough or if it's stripped off by the blustery solar wind. Thermal escape in particular favors the loss of lighter molecules, because at a given temperature a lighter molecule zips around faster than a heavier, tortoise-like molecule.

Losing so much atmosphere would have left Mars much colder and drier. Liquid water wouldn't have lasted on the surface. Geological features suggest that Mars transitioned from warm and wet to cold and dry by roughly 3 billion years ago. But scientists don't know exactly how long it took for the planet to lose most of its atmosphere or why. That's why they built MAVEN.

The Chronologists' Tools

MAVEN's time-travel abilities are limited: it won't flash back 4 billion years to watch the planet's envelope dwindle away. Instead, it'll find out how the various ways of losing atmosphere work and interact today. Then scientists can extrapolate those findings back to the past.

The correspondence between what happened then and what's happening now won't be perfect. The effectiveness of each loss process has likely changed over time — for example, in the early solar system the Sun put out a stronger solar wind and more intense ultraviolet radiation, both of which drive atmospheric escape. But the processes themselves remain the same. If scientists can figure out what the Red Planet's escape rates are today and which processes cause the escape, they will be able to (hopefully) work backward to find out what happened in the past, explains mission principal investigator Bruce Jakosky (University of Colorado at Boulder).

The orbiter has two solar-panel-paved wings that curve slightly to make the craft more aerodynamic. These stretch from both sides of a thermally shielded box that wears what looks like a lampshade (its the main communications antenna). Wingtip to wingtip, the craft spans 11.4 meters (37.5 feet), the length of a school bus.

MAVEN has three instrument packages:

The **Remote Sensing Package**, an imaging ultraviolet spectrometer, will determine the global characteristics of the upper atmosphere and its partially ionized component (the ionosphere), which are where the solar wind and the planet's atmosphere meet.

The **Mass Spectrometry Instrument** will measure the composition and isotopic ratios of neutral gas and ions.

The **Particles and Fields Package** includes six instruments. These will characterize the magnetic-field-infused solar wind and its interaction with the planet's upper atmosphere and localized magnetic fields that stick out of the planet's crust. Part of this work involves looking at the characteristics of electrons in the ionosphere and what the magnetic environment is like.

Daredevil Diving

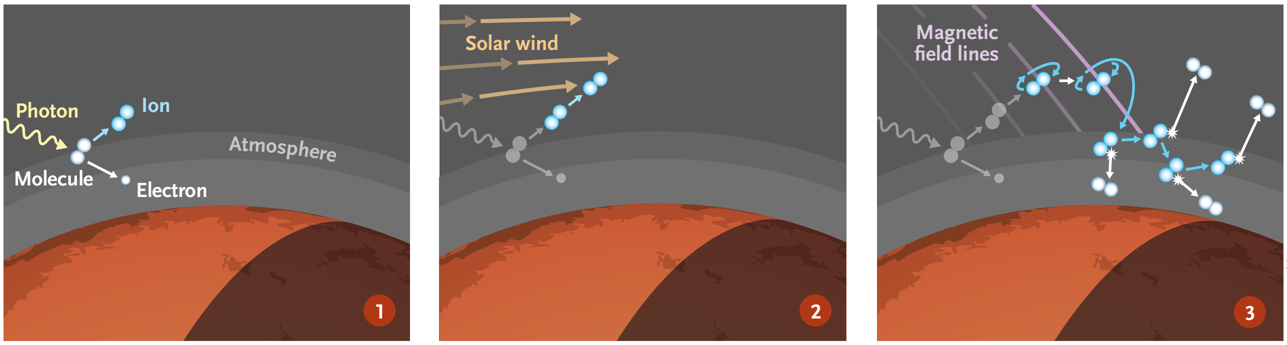
During its 1-year nominal mission, the orbiter will investigate how the planet loses ions and neutral gases. During that year it'll zip in and out of the atmosphere roughly 2,000 times. When the spacecraft reaches Mars in September (the same month as India's Mars Orbiter Mission, or MOM; see page 24), it will enter a highly elliptical orbit of 4.5 hours that swoops down to 150 km (93 miles) from the surface — low enough to dip into the upper atmosphere and directly sample its composition. At its farthest distance of 6,000 km, the spacecraft will image the entire planet's disk with its ultraviolet spectrometer.

MAVEN will also take five "deep-dip campaigns" down to 125 km, diving to the top of the well-mixed lower atmosphere (a.k.a. the atmosphere in bulk, which Curiosity samples from the ground). Each dip is over a different part of Mars and at a different time of the Martian day, enabling the team to measure the Sun's varying influence on the atmosphere. But even with the solar panels' aerodynamic curve the craft can't take too many dives,

COMETARY TROUBLEMAKER

One complication for MAVEN might be Comet Siding Spring (C/2013 A1). The comet will pass 138,000 km from Mars on October 19th. Comets bring lots of debris, and it's hard to say whether that will endanger MAVEN, MOM, or the three other Mars orbiters currently operating. Mission planners are developing "mitigation plans" — such as determining which side of the spacecraft is hardiest so that they can point that side at the dust flow and protect the craft. Read more about the comet at **http://mars.nasa.gov/comets/sidingspring**.

One of the ways the solar wind can steal a planet's atmosphere is by a process called sputtering. In sputtering, the atmosphere actually works against itself. First, high-energy ultraviolet photons from the Sun knock electrons out of atmospheric atoms and molecules, forming electrically charged ions in the Martian upper atmosphere (1). These ions are picked up by the solar wind (2), which is infused with the Sun's magnetic field. The ions circle around the magnetic field lines. As the field-carrying solar wind moves by, it drags these ions with it. Some of these ions, as they are circling, are flung back into the upper atmosphere at high velocity (3). There, they collide with neutral atoms and molecules and knock them every which way, like the cue ball scatters the other billiard balls in a break shot in pool. Some of the atoms are knocked upward with enough velocity to escape Mars — in other words, they're "sputtered."



CASEY REED (3)

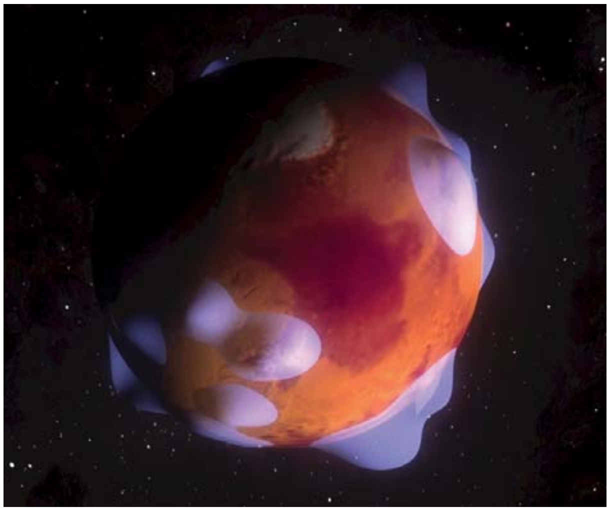
lest the drag forces act as aerobraking and alter its orbit. The denser atmosphere might also facilitate sparking on the instruments.

One thing MAVEN isn't looking for is methane (CH_4), despite multiple observations from Earth-based telescopes and Martian orbiters suggesting that it exists in the planet's atmosphere. Methane is the most common hydrocarbon in the solar system, but on Mars it's unstable on long time scales. Something must replenish it. On Earth, that "something" is biological activity.

So far, NASA's Curiosity rover has yet to sniff out any methane, at least convincingly (*S&T*: Dec. 2013, p. 16). MAVEN doesn't have the spectroscopic range to detect methane, but MOM does. The two teams hope to coordinate some of their observations.

MAVEN will also complement Curiosity. While the rover measures the composition of the well-mixed lower atmosphere, the orbiter will watch the escape of specific gases high above. The rock samples that the rover analyzes also contain embedded fingerprints from the environment in which they formed. Those snapshots of Martian history will help anchor the MAVEN team's extrapolations of atmospheric loss over time.

The team designed the mission to answer all its science questions in one year, but the craft has enough fuel to last about a decade. Mission planners purposefully chose to have the orbiter reach Mars just after the solar cycle reaches maximum, because solar activity is often most volatile during this post-peak period. An extended mission would provide more information about how the changing solar cycle affects the planet's atmosphere.


NASA / GSFC

Mars's global magnetic field is long gone, but localized fields (purple) still emanate from its crust. Some of these mini magnetospheres reach into the planet's upper atmosphere.

Magnetic Marvels

Mars doesn't have a global magnetic field today, but it once did. Localized regions of magnetism, called *remanent fields*, emanate from parts of the surface that both melted (thanks to huge impacts, for example) and then cooled back down during the early era when Mars still had its global shield. As the rock cooled, the planet-wide magnetic field basically imprinted itself onto the crustal material, remaining frozen in place long after the global magnetosphere disappeared.

India's Mission to Mars

The Indian Space Research Organisation (ISRO) launched its own Mars orbiter on November 5, 2013, two weeks before NASA launched MAVEN. India's Mars Orbiter Mission, or MOM — informally dubbed *Mangalyaan* ("Mars Craft" in Hindi) — will study the composition of the planet's surface and atmosphere from space.

Like MAVEN, MOM will arrive at Mars in September. The Indian team will maneuver the spacecraft during its 300-day interplanetary voyage with help from NASA's Jet Propulsion Laboratory, using NASA's Deep Space Network to monitor the craft's trajectory. After MOM fires a braking rocket, the spacecraft will slip into an elliptical orbit that ranges from 350 to 80,000 km (220 to 50,000 miles) above the Martian surface — significantly farther out than MAVEN will orbit.

The MOM spacecraft carries a science payload of 15 kg (33 lbs) that includes five instruments: a Lyman-alpha photometer, methane sensor, quadrupole mass spectrometer, thermal infrared imaging spectrometer, and tri-color camera. These will work together to conduct a global survey of the Martian atmosphere and surface.

One high-level objective is to look for traces of methane. Although NASA's Curiosity rover has not conclusively detected this gas from inside Gale Crater, Indian scientists point out that the atmosphere in Gale might not reflect the situation across the Red Planet.

MOM might be the cheapest mission to Mars ever flown. In August 2012 the Indian government approved $73 million for this project — about one-tenth of MAVEN's $671 million budget. To save money, the Indian space agency used the ground systems and launch vehicle already used for India's lunar orbiter, Chandrayaan-1, which operated from October 2008 to August 2009.

Former S&T *intern* **Shweta Krishnan** *is a freelance journalist in Kilpauk, India.*

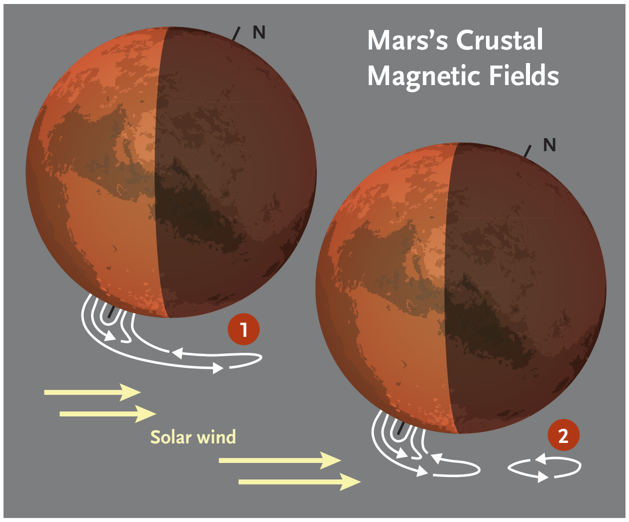
One way to imagine these fields is to think of big magnetic bubbles sticking up from the surface and into the upper atmosphere. The features look somewhat like the localized magnetic structures rising from the Sun's photosphere. In fact, in terms of magnetism, the Red Planet resembles the Sun more than it does the other planets of the solar system.

These remanent fields are absent from Hellas Planitia as well as several other large impact basins. The number of craters in Hellas's interior pegs the basin's formation to about 4 billion years ago. Because of this estimate, many scientists interpret the missing magnetism to mean that the planet lost its global field before the impact that created Hellas.

Not everyone is convinced: some researchers argue that the global field might have survived until 3.6 billion years ago. This argument cites remanent fields in regions covered by volcanic flows, which have younger surfaces. But Mars's remanent magnetism emanates from massive, solidified flows below the surface and not on it, making it difficult to tell whether the magnetic imprints are actually the same age as the surface flows. Crater estimates don't have this same ambiguity, hence the popularity of the 4-billion-year cutoff.

Why Mars lost its global field is an open question. To maintain a magnetosphere, the planet would need to rotate quickly and have lots of convection in a conducting liquid-metallic core. This convection can occur when heat flows outward from the core to the surrounding mantle fast enough to trigger the conveyor-belt-like motion.

The most straightforward explanation for the shutdown of Mars's global magnetism is that the planet cooled enough to turn off convection. On the other hand, impacts might have stifled the flow by heating the upper mantle, especially if the field was already in decline. Mars certainly endured its share of planetary punches in its first few

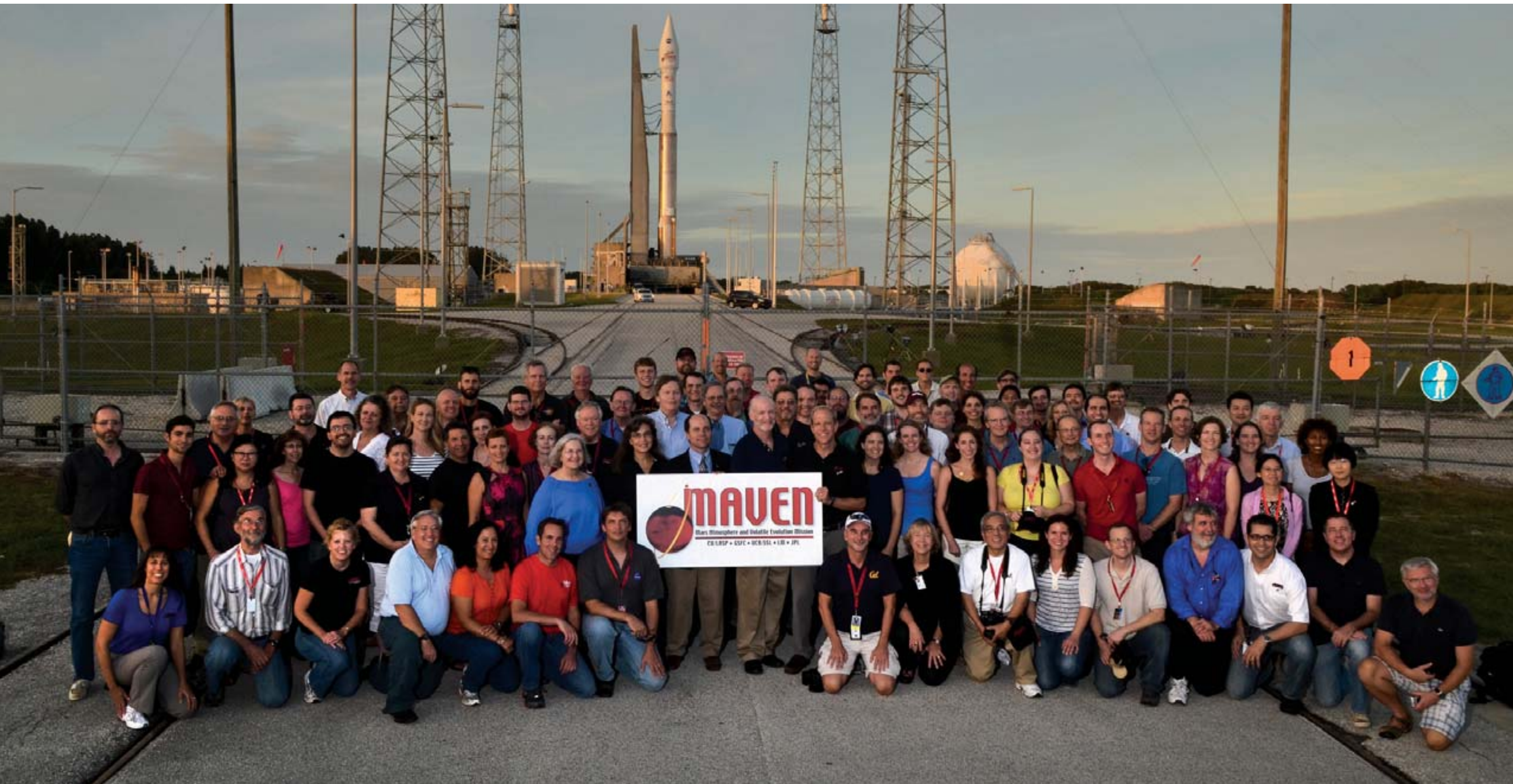


CASEY REED

The solar wind stretches Mars's crustal magnetic fields into giant windsocks (1). Spacecraft observations suggest that the tops of the fields can then snap off, carrying pockets of the planet's atmosphere away with them (2).

Members of the MAVEN team gather in front of the spacecraft atop its Atlas V rocket at Cape Canaveral's Space Launch Complex 41. The rocket launched successfully the following afternoon on November 18, 2013.

MAVEN / CASEY A. CASS (UNIVERSITY OF COLORADO)



HAP GRIFFIN

NASA's MAVEN orbiter launched on November 18th without incident, the beginning of a 10-month journey to the Red Planet. Arrival is scheduled for late September 2014.

Watch videos from the MAVEN team about the mission and the science behind it at skypub.com/mavenvideos.

hundred million years — one doozy of a smash might have excavated the giant depression in the planet's northern hemisphere. But it's still unclear why the field died and whether it was a slow, peaceful death or a more violent one.

Either way, all that's left is the remanent magnetism. Trapped in the subsurface crust, these weak magnetic bubbles rotate with the planet, making their interaction with the magnetized solar wind incredibly complicated. The solar wind can stretch them out like magnetic windsocks behind the planet. They partially shield Mars from incoming energetic particles, although work by MAVEN coinvestigator David Brain (University of Colorado at Boulder) and others suggests that the solar wind might occasionally snap off the tops of these windsocks, carrying away pockets of atmosphere.

In fact, scientists aren't even certain that a magnetic field is always a good thing for preserving a planet's atmosphere. The field might instead help draw energy from solar wind particles into the atmosphere, boosting escape rates. Mars is a perfect place to test whether global magnetism really acts as a "big sneeze guard," as Brain puts it, because the planet is only partially shielded.

Because MAVEN will dive down over different parts of the planet and at different times of the Martian day, its instruments will be able to study in detail how the solar wind and the crustal fields interact. The spacecraft is equipped to detect any crustal fields snapping off, but whether it actually *will* detect these events depends on how frequent the phenomenon is. Brain likens the process to a dripping faucet: bursts of atmospheric escape probably happen intermittently, but there's no steady stream.

Next Stop: Mars

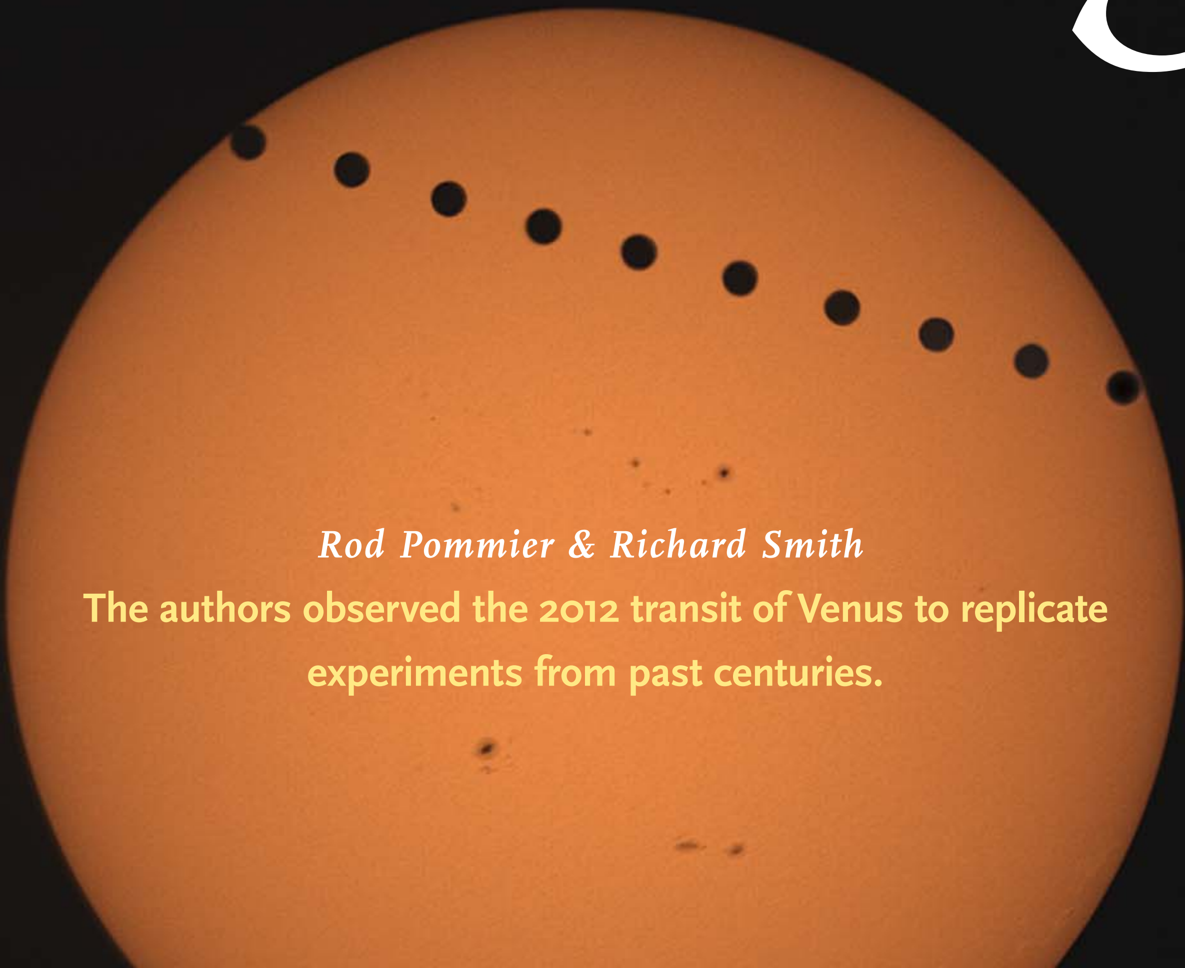
MAVEN's systems thus far check out A-OK. "I think the hard work and incredible management — and I can say that because that's not me — is really showing itself now, because everything is working exactly as expected," says Jakosky. He also notes (with perhaps a touch of glee) that MAVEN has stayed on schedule and on budget.

It'll take time to understand how the instruments are working and to interpret the first rush of data, so there won't be next-day results once the spacecraft enters orbit. The team anticipates having preliminary results about 3 months after MAVEN arrives at Mars.

But perhaps by this time next year, we'll have the pieces we need to start solving the puzzle of how the most Earth-like planet in our solar system (other than Earth itself) evolved from a clement world to the utterly desolate one we see today. ✦

Mars's crustal magnetic fields boggle assistant editor ***Camille M. Carlisle****'s mind. This article is based on her previous coverage of MAVEN for* S&T*'s news blog and its special issue* Mars: Mysteries and Marvels of the Red Planet*, published earlier this year.*

Reliving



Rod Pommier & Richard Smith

The authors observed the 2012 transit of Venus to replicate experiments from past centuries.

Thousands of people traveled great distances to observe the final transit of Venus in our lifetimes on June 5-6, 2012. Transits of Venus are extremely rare, occurring in pairs 8 years apart followed by intervals of more than a century. Each transit is a historical event, but they were particularly important to astronomers of previous centuries because they provided, in theory, a good way to measure the actual distances between the planets and the Sun.

Kepler's third law of planetary motion, which states that the square of a planet's orbital period is proportional to the cube of its distance from the Sun, had profound implications. Knowing each planet's orbital period, astronomers had calculated all their relative distances, expressed as units of the unknown mean distance from Earth to the Sun — the astronomical unit (a.u.). The problem was that nobody knew any of the actual distances. If astronomers knew the actual distance between any two objects, then they could calculate all distances in the solar system, including the a.u.

In 1716 Edmond Halley proposed observing the 1761 and 1769 transits of Venus from widely separated locations to determine the distances to Venus and the Sun. Slight differences in transit duration would permit accurate placement of the apparent position of the transit lines on the Sun's disk. The angular separation between transit lines could then be measured in degrees. If the distance between observers was known precisely, simple trigonometry would yield the distance to Venus and the a.u. The technique relied heavily on precise timing of the moments when Venus's

History

disk, silhouetted on the Sun, just touched the solar limb at ingress and egress, known as second and third contact.

The 18th-Century's Holy Grail

Observing the transits of Venus to determine the a.u. became the holy grail of 18th-century astronomy. The transits spawned some of the first great scientific expeditions, with observers traveling to remote destinations carrying crates of fragile telescopes and instruments. Astronomers would compare their observations with those in other locations. Unfortunately, making the observations was not as easy as Halley had imagined and astronomers encountered a multitude of problems, including clouds, warfare, and disease.

Because of various difficulties, only a handful of successful observations were made of the 1761 transit. They yielded a.u. values ranging from 77.86 to 96.19 million miles (125.30 to 154.80 million km).

For the 1769 transit, Britain dispatched Captain James Cook to Tahiti, but his party's observations were thwarted by the *black-drop effect*. Venus's disk did not appear to touch the inside of the Sun's limb for only an instant. Rather, Cook and his companions saw a thin, dark bridge between Venus and the Sun's limb that persisted for about a minute. The effect prevented his group from timing the exact moments of internal contact to any degree of certainty. Still, more groups observed the 1769 transit, and they narrowed the a.u. to between 92.03 and 96.16 million miles. But the 4-million-mile range was still too imprecise to nail down important planetary parameters.

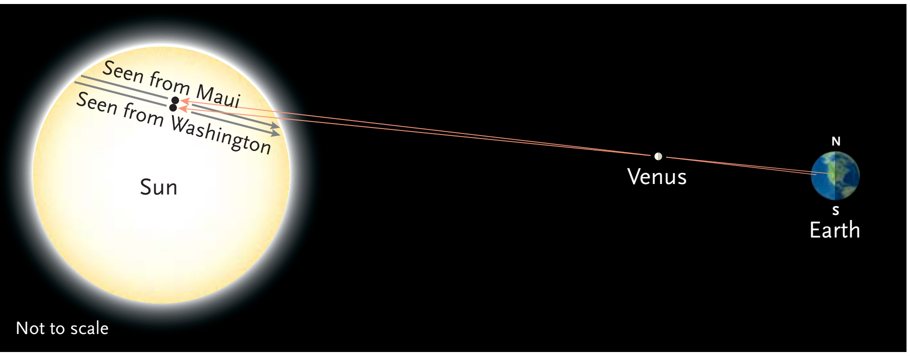
Facing page: **Coauthor Rod Pommier recorded this sequence of Venus's transit across the Sun on June 5, 2012, from the summit of Haleakalā on the Hawaiian island of Maui.**

For the transit of 1874, many more nations joined the quest. Although visual timings of second and third contact were still the goal of most expeditions, some relied heavily on the new technology of photography. Astronomers hoped photography would produce objective records that were not subject to optical illusions, which was suspected to be the cause of the black-drop effect. Unfortunately, the black-drop effect was plainly evident on photos, rendering scores of images useless. Ultimately, estimates of the a.u. from the 1874 transit were scarcely better than those from the 18th century. By the time of the 1882 transit, Scottish astronomer David Gill had nailed down the a.u. by measuring the parallax of Mars.

2012: Amateurs Join the Fray

Given the interesting history of using transits of Venus to measure the a.u., many amateur astronomers wanted to attempt their own measurement during the 2012 transit. There were plentiful opportunities for observers of all skill levels. For example, a NASA website offered three ways for the public to estimate the a.u. The simplest was to measure and upload the diameters of the Sun and Venus in images taken during the transit. At the high end, amateurs could replicate Halley's method by record-

Edmond Halley conceived this geometric method for measuring the astronomical unit (a.u.). The authors observed the June 5-6 transit of Venus from widely separated locations on Earth. They were able to detect the planet's subtle shift (parallax) as seen on the Sun. After using GPS to calculate their baseline distance, they applied basic trigonometry to calculate the distance to Venus and the a.u.



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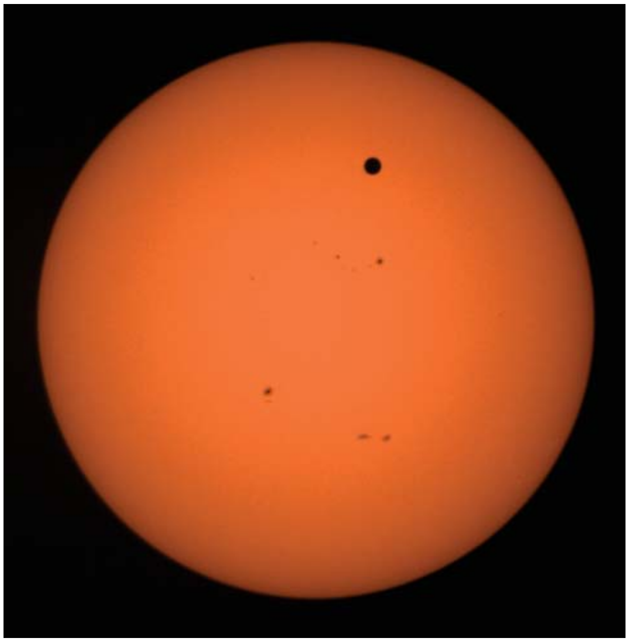


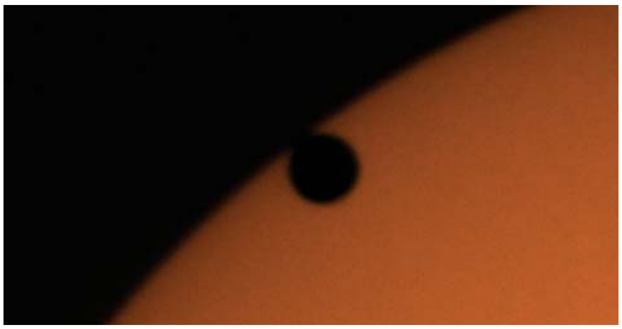
ROD POMMIER (2)

Left: **Coauthor Rod Pommier and his wife SuEllen pose near the summit of Haleakalā on June 5, 2012. Rod brought his 8-inch Celestron SCT, tripod, wedge, full-aperture solar filter, and Canon 20D DSLR to the summit to photograph the entire transit. The Haleakalā Observatory complex is visible in the background.** ***Right:*** **Pommier took this image of the transit with his SCT. Unlike Smith's image on the facing page, no clouds are visible.**

ing the times of second and third contact from widely separated locations.

Other amateurs attempted to measure the a.u. with their own independent observing projects using Halley's original method. This required the coordination of observations between astronomers in widely separated locations. Some projects were organized within or between astronomy clubs. Some were organized over long distances via the internet. Others were organized between friends within the amateur community.

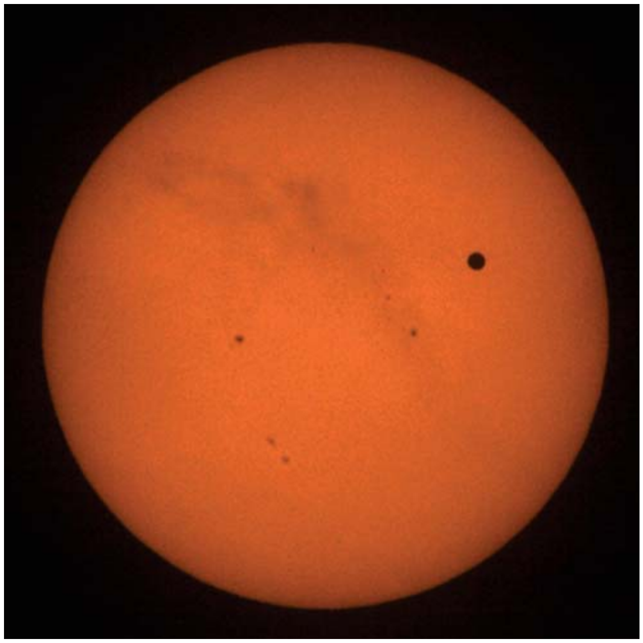
The two of us were also eager to emulate astronomers of prior centuries by taking advantage of the 2012 transit. Richard would play the role of an 18th-century astronomer remaining in Greenwich or Paris. He would observe a partial transit from his home in West Richland, Washington, using his 8-inch f/8 Cave Astrola Newtonian telescope. Rod would be like Captain Cook, traveling to a Polynesian island. He journeyed from his home in Portland, Oregon, to the summit of Haleakalā on the Hawaiian island of Maui, where the entire transit would be visible and, at an elevation of 10,000 feet, he'd likely be above any clouds. He would bring his 8-inch Celestron SCT with an f/6.3 focal reducer, yielding a focal length of 50 inches



Rod Pommier took this image around second contact, clearly showing the black-drop effect. This optical effect thwarted efforts to measure the a.u. using the transit of Venus since Captain Cook's expedition to Tahiti in 1769. The effect renders it nearly impossible to determine the precise moment when Venus makes internal contact with the Sun's limb.

We would each photograph the transit through our telescope using a Canon 20D DSLR camera. We'd use Richard's images to produce a composite image with a partial transit line and use Rod's images to produce a composite image with a complete transit line. After measuring the parallax angle between the two transit lines, we'd use the distance between West Richland and Haleakalā to calculate the distance to Venus and thus the a.u. Historically, using transit lines has been considered more accurate than directly measuring Venus's parallax. Although Venus has the largest apparent diameter of any planet, its disk is still quite small, making direct measurement of parallax difficult.

On June 5th, Richard awoke to completely overcast skies. Hoping for improving weather, he set up his telescope, but there was no change when the transit began at 3:05 p.m. PDT. At 5:00 p.m., there was still no improvement and the forecast called for continued clouds. Richard concluded he would not see the transit at all, so he took down his telescope and went indoors.



Left: **Coauthor Richard Smith stands next to his 8-inch Newtonian with which he planned to shoot the transit from his home in West Richland, Washington. Unfortunately, he eventually took it inside due to continuous overcast skies.** ***Right:*** **During a brief break in the clouds, Smith captured this image with a 400-mm telephoto lens attached to a Canon 20D DSLR. This image was taken within seconds of Pommier's image on the facing page.**

At 6:25 p.m., he was elated to see sunlight inside his house. Looking outside, he saw the Sun through a small break in the clouds. He didn't think the break would last long enough to set up his telescope again. Fortunately, he had a 400-mm telephoto lens with a solar filter. He quickly attached them to his DSLR and rushed outside. There were only intermittent breaks in the clouds through which he could take images before clouds again covered the Sun for the remainder of the day. A transit line for Richard was not to be, but he was thrilled to have seen and captured some images of the transit.

Rod carefully packed his equipment in padded cases for the trip to Maui. On June 5th, he and his wife, SuEllen, drove to the summit of Haleakalā and set everything up.

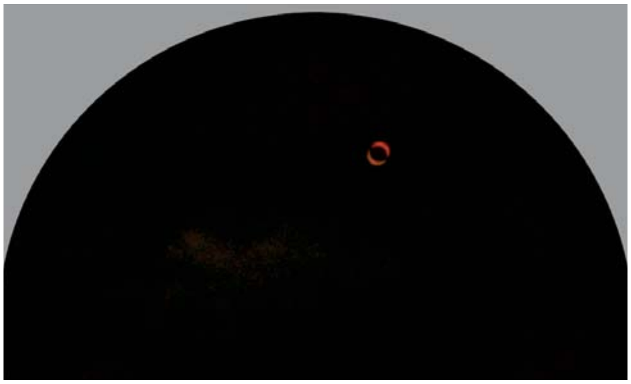
Although much of Maui was overcast, skies at the summit were crystal clear. But winds gusted to 50 miles per hour! Rod hung his tripod case beneath the mount and filled it with lava rocks to prevent his telescope from being blown over. At ingress and egress, he observed the black-drop effect that thwarted Captain Cook and other observers in prior centuries. Both black-drop effects lasted about a minute. Rod also measured the diameter of Venus's disk as 58 arcseconds using a crosshair reticle. The expedition was a great success, capturing the entire transit on hundreds of images.

Mathematical Machinations

After the transit, we compared our photography logs. Despite the fact that the times of Richard's photographs were dictated by cloud breaks, DSLR time stamps indicated that seven were taken within seconds of three images taken by Rod. Therefore, it would still be possible to calculate the distance to Venus and the a.u. using the more difficult technique of directly measuring the parallax of Venus's disk.

GPS devices determined the latitudes and longitudes of our West Richland and Haleakalā observing sites with an accuracy astronomers of prior centuries could not have imagined. Richard used the GPS coordinates in a mathematical model that compensates for Earth's slightly oblate shape to precisely calculate the through-the-Earth baseline distance between us, including a contribution from Haleakalā's nearly 2-mile elevation, as 2,670.453 miles. When Richard took his images, West Richland was nearing Earth's western limb as viewed from Venus and the Sun. That would result in some apparent foreshortening of the baseline distance. Further trigonometric calculations indicated a foreshortened baseline of 2,213.197 miles.

Rod upsized Richard's images to match and align the Sun's disk to that in his images. Sunspots provided good reference points for rotating Richard's images. The aligned images were put in the Layers Palette in *Photoshop* with Rod's image as the upper layer. Applying the "Difference" Blending Mode blacked out all similar portions of the images, revealing only the areas where Venus's disks did not coincide. Venus's parallax could be seen as two bright crescents, pointing in opposite directions. Each image pair was flattened, embedding the brightness levels of the two parallax crescents into the pixels of the higher-resolution upper image.



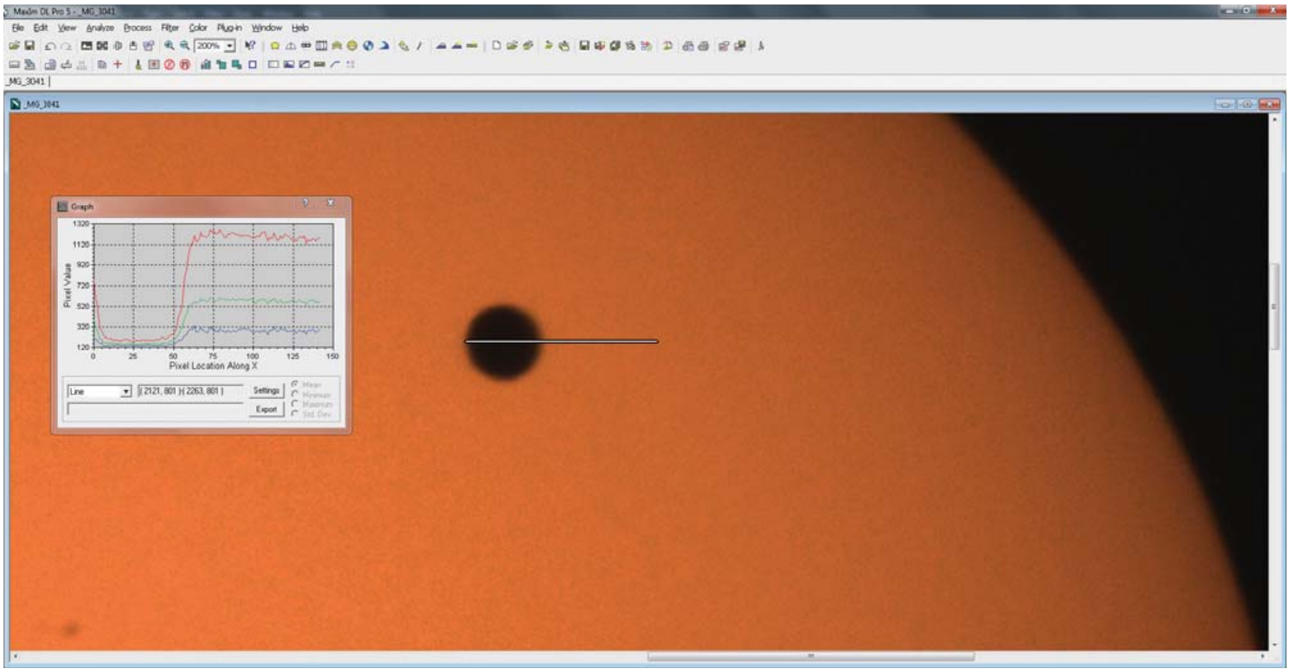
ROD POMMIER / RICHARD SMITH

The authors aligned and superimposed their photos on the previous two pages to create this image. By stacking and processing the images in *Photoshop*, all similar portions of the image were blacked out. Venus's parallax appears as two bright crescents pointing in opposite directions, indicating only the portions of Venus's disk that did not coincide in the two pictures.

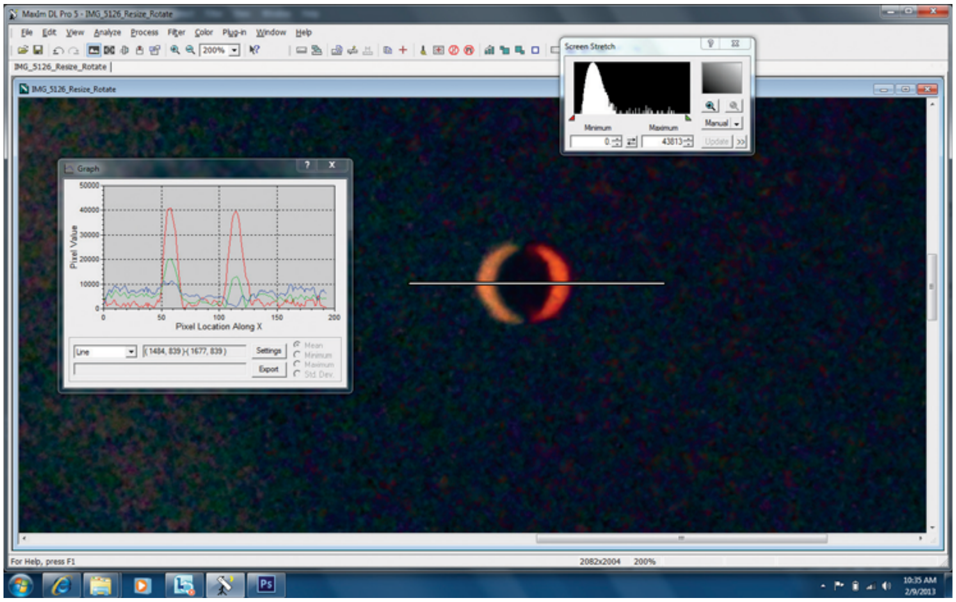
Using *MaxIm DL*'s Graph Function, the average diameter of Venus's disk in Rod's images was 55.33 pixels. Because Rod measured Venus's diameter as 58 arcseconds, the image scale was 1.05 arcseconds/pixel. We also used the Graph Function to measure the width of the bright parallax crescents in each flattened "Difference" image. The dual crescents permitted two measurements of the parallax per image, which would help average out motion and seeing artifacts. The crescents produced tall twin peaks in the red channel on the graphs. We drew lines along each side of the peaks and projected down to the x-axis to read the width of each peak in pixels. The average of the 14 readings was 21.78 pixels. Multiplying that by the image scale yielded an average parallax of 22.83 arcseconds.

But this measured result is not just the parallax of Venus; it's the combined parallaxes of Venus and the Sun. Even the Sun has a parallax for observers separated by 2,213 miles. Thus, when Rod aligned the Sun in Richard's images to the Sun in his pictures, he added the Sun's parallax to Venus's parallax. We would have to know the distance to the Sun, the very value we seek, to calculate its expected parallax and subtract it from the total measured parallax to get Venus's individual parallax, which is what we needed to calculate the distance to the Sun. This paradoxical problem seemed circular and insoluble. Fortunately, an elegant mathematical solution exists that doesn't require any a priori knowledge of the Sun's distance.

The total measured parallax can be used to calculate an approximate distance to Venus. That permits calculating an approximate distance to the Sun using Kepler's third law. That can then be used to calculate a rough estimate of the Sun's parallax. That estimate can be subtracted from the original total parallax, yielding a better estimate of Venus's parallax. The revised Venus parallax can be used to repeat the calculation, yielding a better result. Multiple iterations of this process will converge



Pommier used *MaxIm DL* to calculate the diameter of Venus's disk in pixels. The graph on the left shows the pixel brightness along the white bar over Venus. One end is on the edge of Venus's disk and the brightness value in the red channel at that point was read on the y-axis. Pommier measured Venus's diameter by determining at which pixel on the x-axis the brightness returned to the same value. Because he measured Venus's disk to be 58 arcseconds across, he could determine that the average image scale in his photographs was 1.05 arcseconds per pixel.



Using *MaxIm DL*, the authors placed the white bar across the Venus crescents at their widest points, producing two peaks in the graph's red channel. They projected lines along the sides of each peak down to the x-axis to read their width in pixels. The left and right crescents had parallaxes of 19 and 22 pixels, respectively. They converted the average parallax in pixels from all the images to a parallax angle in arcseconds. Using the math described in the text, Venus's calculated parallax yielded a distance to the planet of 25.8 million miles, 3.9% less than the correct distance of 26.8 million miles. This yielded an a.u. of 89.3 million miles.

on the individual parallaxes of Venus and the Sun. Any errors in the final results will be proportional to the error in the original total parallax measurement.

We began our distance calculations by applying the arctangent of half the parallax angle of 22.83 arcseconds to half of the foreshortened baseline to estimate rough distances to Venus and the Sun. Multiple iterations of the above process converged on individual parallaxes for Venus and the Sun of 17.72 and 5.11 arcseconds, respectively (the expected values were 17.00 and 4.99 arcseconds). Our final trigonometric calculation using half of Venus's individual parallax of 17.72 arcseconds yielded a distance to Venus of 25.8 million miles. The actual distance between the centers of Earth and Venus was 26,836,434 miles, for an error of –3.9%. Our calculated a.u. using Kepler's third law was 89.3 million miles, naturally also an error of –3.9%.

How Could We Have Done Better?

For this 21st century transit, modern technology enabled us to virtually eliminate errors in determining the latitudes, longitudes, and times of our observations. So, what else could we have done better to improve our results? If Richard had better weather, he could have taken images with his telescope instead of his telephoto lens, providing higher resolution. Better weather in West Richland also would have permitted Richard to take more images, which might have averaged out more errors.

If Rod had traveled to Tahiti or Australia, we would have measured a larger parallax. Rod also could have measured Venus's diameter correctly at 57.78 instead of 58 arcseconds. Rod could only register images and measure the parallax to the nearest whole pixel. One pixel made a difference of 1.05 arcseconds, changing the distance to Venus by more than a million miles and the a.u. by several million miles. This underscores the technique's extreme inherent sensitivity of the results to even tiny observational errors.

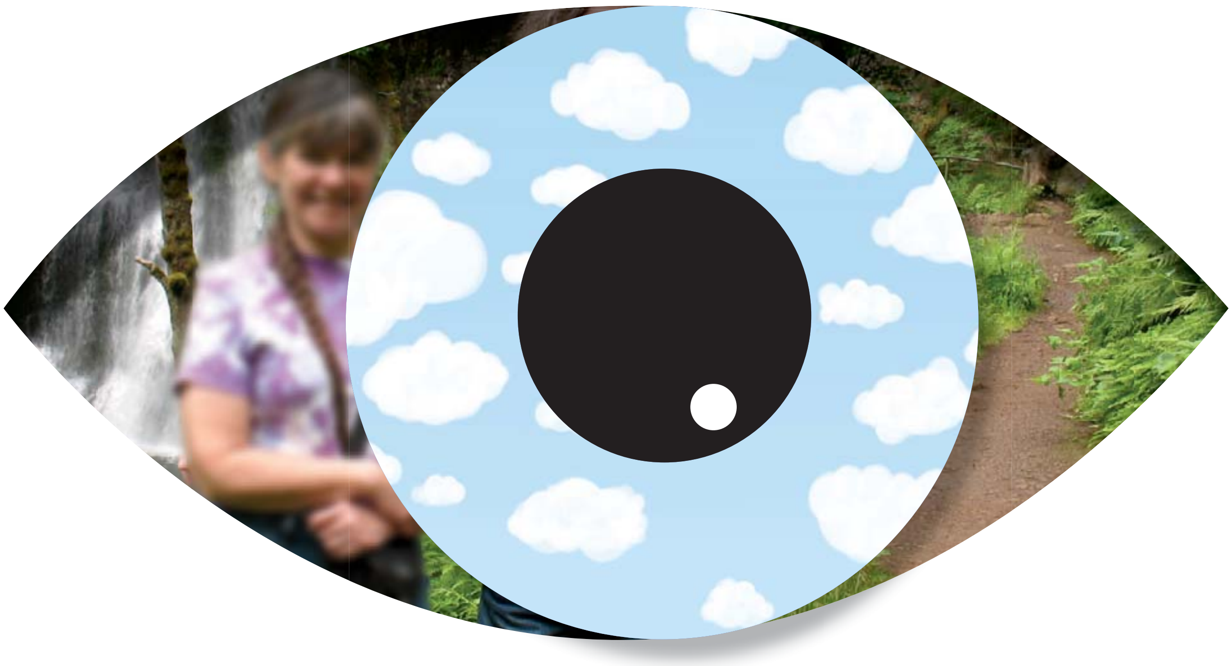
We actually came within a fraction of an arcsecond (less than one pixel) of the expected parallax result, yet we ended up with a –3.9% error. This difficulty is borne out in a review of results from other successful amateur projects posted on the internet. They indicate results ranging from an error very close to ours extending up to 5%.

Our experiences and problems were remarkably similar to those of astronomers in prior centuries. They had to compare observations made with instruments of different focal lengths. Many also encountered clouds, which permitted them to make only a few observations, or none at all. Circumstances often prevented them from traveling as far as they would have liked. The graininess of their photographic plates limited their accuracy in measuring Venus's parallax.

The similarities between their problems and ours made our experiences all the richer. We personally relived that history, giving us a feeling of connection to observers of prior centuries. Accordingly, we don't view our –3.9% error as a failure, but as yet another similarity. Expeditions of previous centuries never determined the correct a.u. value either, and we got about as close as many of them did. Actually measuring the distance to Venus and the a.u. with our own observations was an extremely rewarding experience that we will remember for the rest of our lives. ✦

Avid astrophotographer ***Rod Pommier*** *is a surgical oncologist and Professor of Surgery at Oregon Health & Science University in Portland.* ***Richard Smith*** *is a retired clinical laboratory technician who has enjoyed amateur astronomy from his college days.*

Clearing the Clouds: Cataract Surgery for Astronomers



Kathy & Jerry Oltion

One amateur's journey through the medical maze of cataract surgery has lessons for any observer facing the same condition.

IMAGINE SMEARING VASELINE all over your primary mirror, then smashing it into several pieces. The view through your eyepiece would not be pretty: it would be fuzzy and broken into multiple images. Cataracts do that to your vision. *Everything* looks like that. Unfortunately, if you live long enough, you're almost certain to develop cataracts (see the box on page 35). Environmental factors, including ultraviolet light from the Sun, gradually destroy the structure of lens proteins, clouding the lens and obstructing vision. Though commonly found in the elderly, cataracts have a number of causes; even newborn babies can have cataracts.

Coauthor Kathy's cataracts developed in her early 50s, just a few years after we became amateur astronomers. She started seeing multiple images of planets and fuzzy halos surrounding bright stars. The brighter the object, the worse it looked. Her eyeglass prescription began to change, skewing radically toward nearsightedness.

Fortunately, cataract surgery has become routine; a surgeon can simply remove the cloudy lens and implant a new one, and then you can go on as if nothing had ever happened, right?

Wrong. That myth applies only if you don't pay much attention to your vision. If patients don't know what a diffraction spike is, they might not notice the new ones in their field of view. But amateur astronomers pay close attention to what we see, and we most definitely notice the effects of cataract surgery. We even hear horror stories of people who have given up astronomy because of what the surgery did to their vision.

That's the bad news. The good news is that if you go into the procedure with both eyes open, so to speak, you stand a much better chance of coming out of it with vision that still works for astronomy.

The Surgery

We had heard other amateurs complain of diffraction effects from lens edges in the light path, so Kathy asked her surgeon for a large lens, one larger than her dilated pupil. But the largest replacement lens he would use was 6 mm, a dicey proposition for a relatively young person whose pupils might still open to 7 mm.

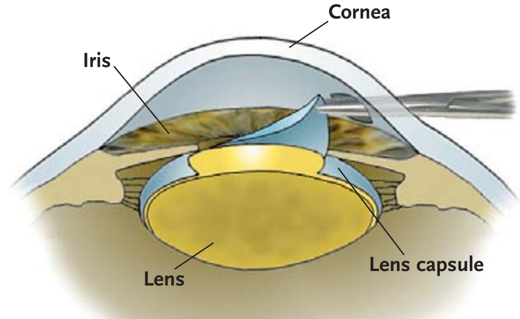
What's worse, the diameter of the replacement lens is only one consideration. When the surgeon removes the natural lens and implants the artificial one, the first step is to remove the front of the lens capsule, a clear, paper-thin sack of tissue that surrounds the lens, in a process called *capsulorhexis*. That opening typically has a smaller diameter than the lens, and for good reason: the lens capsule helps hold the lens in place, and a smaller opening helps prevent the migration of loose lens cells that might later cause cloudiness in the rear part of the lens capsule. But the smaller diameter of the capsulorhexis meant that Kathy didn't get a 6-mm clear aperture when she chose a 6-mm lens; the aperture was closer to 5 mm.

That was still better than having cataracts, so Kathy went ahead with the surgery. Cataract surgery is done one eye at a time. After the first operation, Kathy immediately noticed two improvements. Not only could she see clearly again in that eye, but because the cataract had been acting as a yellow filter, everything looked bluer, too. For the first few hours, she was very pleased with the outcome.

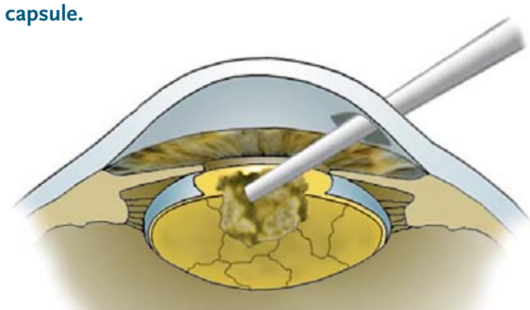
However, the moment she looked at a bright light that evening, she knew something was wrong. The eye with

What Is a Cataract?

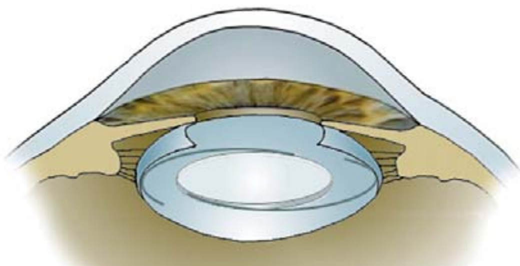
The eye's natural lens consists mostly of long, thin, transparent cells called lens fibers. Over time, ultraviolet light from the Sun, and a host of other factors such as trauma or diabetes, can damage proteins in these cells, hardening and clouding the fibers. The cells change their index of refraction as a result, and they don't do so uniformly. Different parts of the lens harden faster than others, creating multiple focal zones. These changes muddy vision and may even create multiple images of the same object.



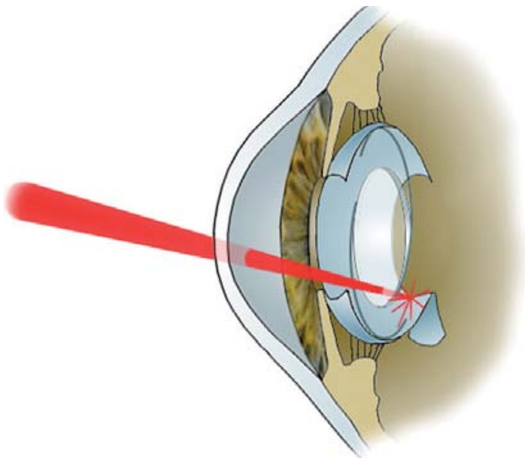
CATARACT SURGERY **These days, cataract surgery is a routine procedure. First the surgeon performs a *capsulorhexis*, carefully removing a front section of the lens capsule.**



Next, the surgeon breaks up the natural lens using ultrasound waves in a process called *phacoemulsification*, then removes the lens fragments from the lens capsule using suction.



Finally, the surgeon inserts the replacement lens, folding the lens to fit it into the incision. Support wires called *haptics* extend from the replacement lens to hold it in place in the lens capsule.

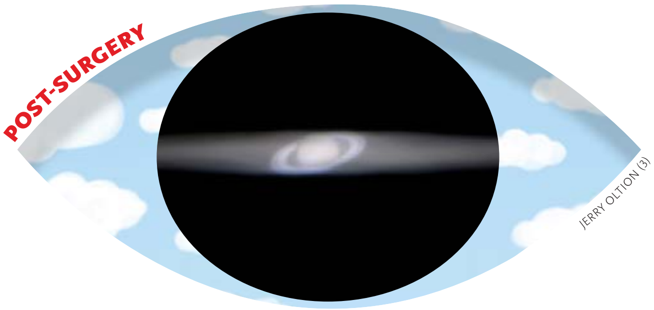


JERRY OLTION (4)

If secondary cataracts develop after the surgery, they are removed with a *capsulotomy*, where the back of the lens capsule is lasered away. The patient sits upright for this follow-up procedure.

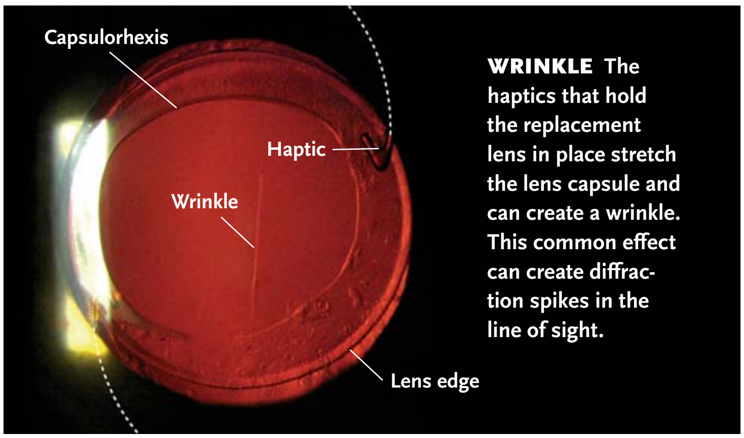
A healthy eye's view of Saturn through a telescope.

Kathy's cataracts blurred and broke up the image.



JERRY OLTION (3)

After her first procedure, Kathy's daytime vision cleared significantly, but a large diffraction spike destroyed her nighttime vision. After both eyes had been operated on, a second diffraction spike (not shown), cocked at a jaunty angle, joined the first.



JERRY OLTION

WRINKLE The haptics that hold the replacement lens in place stretch the lens capsule and can create a wrinkle. This common effect can create diffraction spikes in the line of sight.

the new lens showed a huge diffraction spike around every streetlight and porch lamp. She saw more of the same when she looked through a telescope. Planets became bright bands stretching all the way across the field of view, as did any first- or second-magnitude star.

Ironing Out the Wrinkles

What had gone wrong? It turns out that the little wires called *haptics* that hold the lens in place were stretching the back of the lens capsule and, like cling wrap stretched unevenly over a bowl, the capsule had wrinkled. The wrinkle produced a diffraction spike far greater than the one caused by the spider in front of a telescope.

Kathy's surgeon wouldn't believe that the wrinkle was causing the diffraction spike. The wrinkle is so common that it's called the "in the bag sign," an indicator that the lens is resting properly within the lens capsule, yet few people complain about it. Many simply give up low-light activities. Incredibly, most people just don't seem to care.

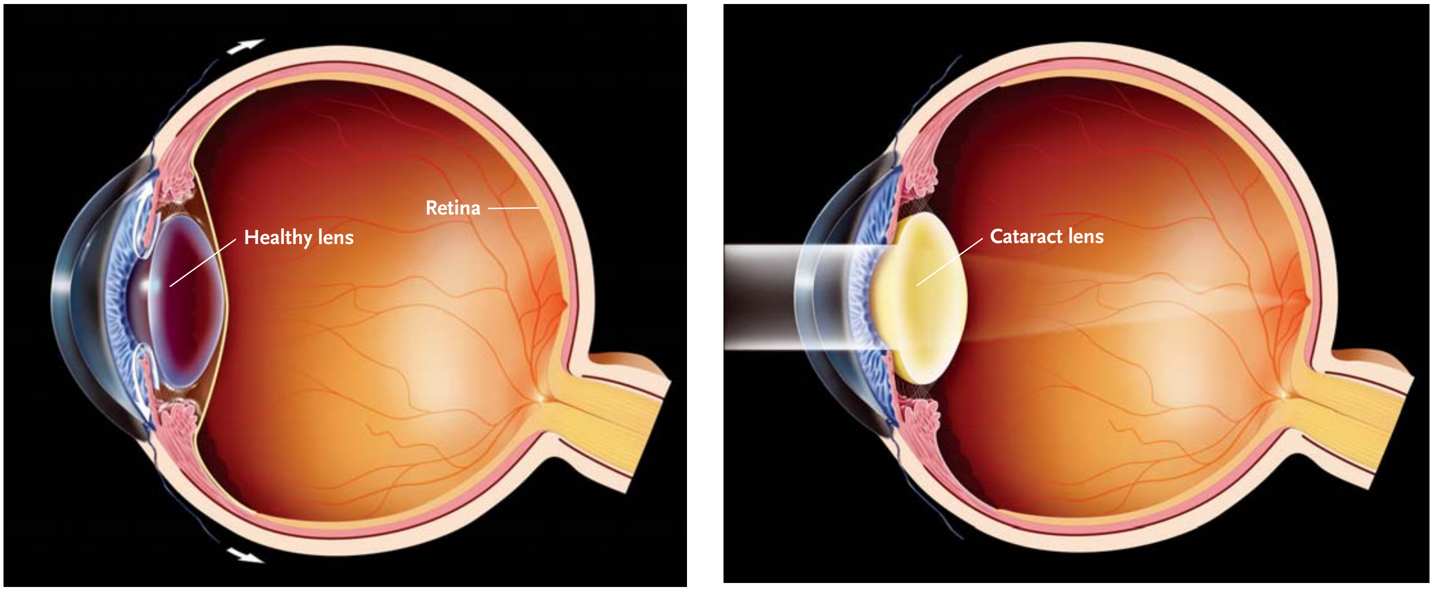
But amateur astronomers care.

Kathy sought out another surgeon for the other eye, and he had good news. He would insert a ring to hold the lens capsule tight so the haptics wouldn't stretch it enough to wrinkle. It was a great idea, except for one problem: the ring didn't work. That's how common the wrinkle is: even efforts to prevent it aren't always effective. Now Kathy had two diffraction spikes coming off every bright light. Like the first one, the second spike was mostly horizontal, but cocked at a jaunty angle from the other, so she now had two wide bands coming off every bright light.

Sometimes the wrinkles go away with time as the capsules shrink around the replacement lenses, but Kathy's wrinkles stayed put. And to add insult to injury, she developed *secondary cataracts*, a common complication where leftover lens cells grow on the back of the lens capsule. Fortunately, the fix doesn't involve another invasive surgery. In a quick and painless procedure called a *capsulotomy*, the doctor uses a laser to remove the hazy section, essentially burning an opening in the back of the lens capsule.

But this procedure provides another opportunity for amateur astronomers to use expressive four-letter words. More diffraction! Surgeons don't like to cut big holes in people's eyes. That's generally a good thing, but with a capsulotomy, a small hole can mean a ragged edge in the light path. Even if the edge is relatively smooth, it's often polygonal, which can produce diffraction spikes going every which way.

Fortunately, our optometrist recommended a relatively new surgeon for the capsulotomies, one who was current on the latest technology and methods. During the pre-operative interview, we impressed upon him the severity of the problems Kathy was having with diffraction and her special concerns as an amateur astronomer. He understood her concerns and promised to make the



JACOPIN / SCIENCE PHOTO LIBRARY (2)

HEALTHY EYE VS. CATARACT Light passes through the lens to reach the retina, where the eye forms an image. *Left*: In a healthy eye, the lens is transparent. *Right*: Ultraviolet light from the Sun and other causes can cloud the lens, forming a cataract. Vision can become cloudy, dim, blurred, yellowed, and/or broken into multiple images as a result. (Not all effects are shown in the diagram.)

biggest capsulotomy that he could make without endangering her eye or the artificial lens. And he promised to make the incision as round as he could.

He was good to his word, and after the procedure Kathy was pleased to see that the diffraction spike had disappeared in that eye. Even with her eye fully dilated at night, she could look at Saturn through a telescope without seeing diffraction.

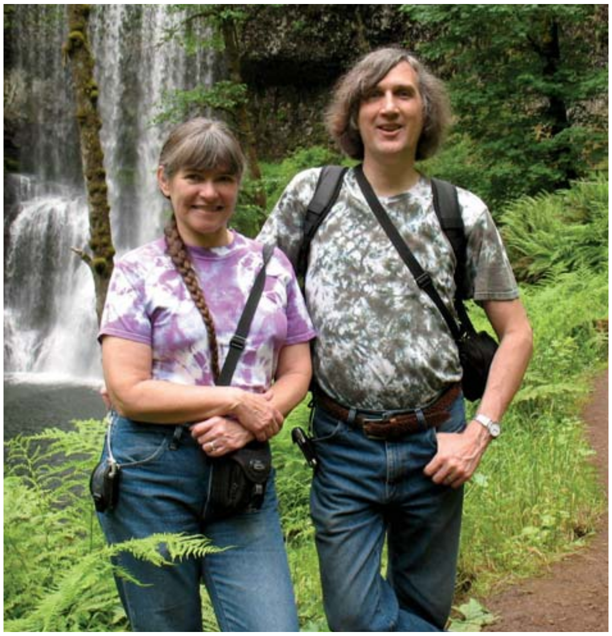
She had the other eye lasered a month later with the same result: the diffraction spike disappeared. She didn't experience any problems from the edges of the capsulorhexes or the capsulotomies, probably because both openings are nice and round. Her eyes now perform as they did before the whole cataract ordeal began, and she looks forward to many more years of astronomy.

Lessons Learned

Though wrinkle-caused diffraction may be considered normal in cataract patients, we discovered you don't have to put up with it. Nor do you have to accept the optical defects that can accompany small capsulorhexes and capsulotomies. As with the rest of our optical train, amateur astronomers want the largest clear aperture we can get — with the emphasis on "clear."

As always when discussing medical concerns, your mileage may vary. Don't take this article as a prescription for what everyone with cataracts should do; rather use it as a guide for discussing your goals as an amateur astronomer with your surgeon. Medical constraints will guide what is possible and safe, but there are also optical constraints as to what's acceptable for amateur astronomy. Make sure both you and your surgeon understand what you want and how to achieve as much of it as medically possible. If you go into cataract surgery informed, you stand a much better chance of coming out happy. ✦

__Kathy and Jerry Oltion__ have been amateur astronomers for about a decade. Jerry builds telescopes and many of his creations have been featured in Gary Seronik's Telescope Workshop column. View their website at __www.sff.net/people/j.oltion.__ They thank Drs. Philip Stockstad, Steven Ofner, Mark Packer, and Matthew Neale for their assistance in restoring Kathy's vision and preparing this article.



JERRY OLTION

Dennis di Cicco

Achieving Stellar Performance


Described in detail in the accompanying text, this view of the well-known galaxy M51 is an excellent example of the resolution and focus stability of the Officina Stellare RiDK 300 astrograph. The author never adjusted the scope's focus during the 15 hours of observing time (spread across two nights) during which he made exposures for the image. The author's colleague, Sean Walker, processed all the astronomical images with this review.

ALL PHOTOS BY THE AUTHOR

Two pieces of premium gear deliver first-class astrophotos from your backyard or from half a world away.

Officina Stellare RiDK 300

U.S. price: $14,695. As tested with the Rotofocuser, $19,454.
officinastellare.com

Software Bisque Paramount ME II

U.S. price: $15,000.
bisque.com

EVERYONE KNOWS the old saying "you get what you pay for." Although it's often the lament uttered for the disappointing performance of bargain-priced products, it's based on the general understanding that truly exceptional-quality stuff isn't cheap. That's the case for two pieces of newly introduced equipment that I've been testing since late last year. Officina Stellare's RiDK 300 astrograph and Software Bisque's Paramount ME II are priced at the upper end of the spectrum in their respective categories. As such, I wasn't just hoping that they'd perform well; I *expected* them to perform well. And preform they did. The scope and mount are truly first-class, and together they enabled me to take some of the finest deep-sky photographs I've ever made from my suburban-Boston backyard observatory.

It would be impossible in the space here to list all the features this equipment has to offer. Furthermore, you'll find extensive specifications and claims of performance on the manufacturers' respective websites, and none of my tests and experiences contradicts any of that material. So rather than a point-by-point review, what follows is some overall information and highlights of my tests. Let's start with the telescope.

Officina Stellare's RiDK 300

The concept of an astrograph based on a two-mirror Dall-Kirkham Cassegrain with an added multi-lens corrector near the focal plane is relatively new. I outlined some of the design's history in a review of the

Left: **With their red-and-black motif, the RiDK 300 astrograph and Paramount ME II make a handsome couple, especially when fitted with the similarly hued SBIG STT-8300 CCD camera. The scope is shown here with its black-cloth shroud covering the truss assembly.** ***Right:*** **The scope is relatively compact, measuring only 45 inches (114 cm) from the front of the tube to the focal plane, which extends 9½ inches out from the scope's back plate.**

WHAT WE LIKE:

Extraordinary image quality

Excellent focus stability

Robust mechanical construction holds collimation extremely well

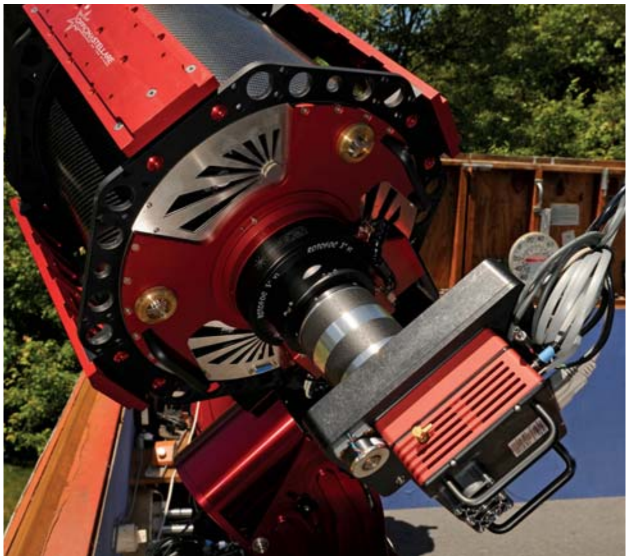
WHAT WE DON'T LIKE:

Built-in dew heaters and cooling fans require an optional controller

PlaneWave 12.5-inch CDK telescope (*S&T:* Nov. 2010, p. 36). As a commercial product, the "corrected" Dall-Kirkham made a cameo appearance when Celestron introduced a 20-inch version in the mid-2000s. Soon afterwards, PlaneWave Instruments was founded by several former Celestron employees, and the company began manufacturing its CDK telescopes. Those scopes helped make the design a household name among today's elite astrophotographers.

In their book *Telescopes, Eyepieces, and Astrographs* (Willmann-Bell, 2012), Gregory Smith, Roger Ceragioli, and Richard Berry heap lots of praise on the concept of a corrected Dall-Kirkham, calling it a "viable alternative to the Ritchey[-Chrétien]" design that has dominated the world of high-end amateur astrophotography for several decades. Now the Italian firm Officina Stellare has introduced a line of high-performance, corrected Dall-Kirkham astrographs created by the company's chief optical designer, Massimo Riccardi. Hence the "Ri" attached to the Dall-Kirkham's "DK" in the scope's name.

People who visited Officina Stellare's display at the 2013 Northeast Astronomy Forum in New York or the 2013 Advanced Imaging Conference in California had a chance to see the telescope I borrowed for my tests. They know it's a strikingly handsome instrument; even better looking in person than it appears in photographs. This is not surprising given that it's from the same country that gave us the Ferrari, Lamborghini, and Sophia Loren. None of this beauty, however, comes at the expense of mechanical performance.



The optional Officina Stellare Rotofocuser ($3,850) proved to be exceptionally precise. Its rotation and focus positions are accurately set from highly repeatable homing positions.

Left: If the optics ever need collimation, a pattern of centered rings printed on the surface of the secondary mirror will help. **Right:** The astrograph's front end is very rigid and, as explained in the text, it held optical collimation exceptionally well. Although the scope has a clear aperture of 305 mm and an f/7.9 focal ratio (as indicated by the printing seen here), its name was recently streamlined to RiDK 300 so it would conform with other instruments in the company's expanding line of astrographs.

From the moment of "first light," I realized that mechanically this scope is special. Although Officina Stellare offers several options for shipping its telescopes, including custom wooden crates, my scope traveled from Italy to New York, then to California, and finally back to Massachusetts in a rather unremarkable cardboard box surrounded by only 2 inches of polyethylene foam. Add to that the rough handling that equipment typically endures when displayed at trade shows, and you can understand why I was expecting the scope to be out of collimation when I finished setting it up in my observatory. It wasn't, and this fact astounded me.

As nights of testing stretched into weeks and then months, another of the scope's mechanical attributes emerged — it has remarkably stable focus over a wide range of ambient temperatures. The image of M51 on page 38 is a perfect example. I obtained the color data for that shot last March 24/25. The scope was focused at the end of astronomical twilight and remained untouched for the next 8 hours as I made 45 back-to-back 10-minute exposures (15 each through red, green, and blue filters). The unfiltered (luminance) data for the image is a set of 37 back-to-back 10-minute exposures made on April 20/21 during a 7-hour stretch when the focus also remained untouched. On both nights the temperature dropped more than 13°F (7°C) during the exposures.

Software for remote control of the Rotofocuser is straightforward and easy to learn just by looking at its user interface.

I was equally impressed with the mechanical quality of the optional Rotofocuser supplied with the scope. It can be operated at the telescope with a small, dedicated control box, or remotely with software (including an ASCOM-compliant version) running on a host computer. Because of the way I configured my remote setup, each night I had to "home" the Rotofocuser to its zero point and then return it to the focus position, which can be specified in 0.1-micron increments. The precision and repeatability of the system is amazing. Combined with the scope's focus stability, it took only a few minutes to manually achieve excellent focus each time I began an observing session. And most nights I never refocused the system.

Finally, there's the RiDK 300's image quality — perhaps the most important aspect of any astrograph. As fate would have it, my night of first light with the scope had unusually good atmospheric seeing, and a couple of 10-minute test exposures (ones that I didn't make dark or flat calibration frames for) had stars only about 1½″ (arcseconds) in diameter. This is extraordinary and something that I rarely achieve from my backyard with large-aperture telescopes.

The image quality was so good that I decided to modify my testing plans. Originally I was going to use a CCD camera with a big KAF-16803 chip, covering a 0.88°-square field of view. But this CCD's 9-micron pixels yielded a scale of 0.77″ per pixel, which is on the borderline of undersampling the scope's small star images. Instead, I did much of my testing with a camera having a smaller KAF-8300 CCD and 5.4-micron pixels that yielded a scale of 0.46″ per pixel.

Eastern Massachusetts spends much of its winter sitting under the jet stream, which rarely allows seeing much better than about 3″. As such, it was unusual for me to image at the RiDK 300's maximum resolution, but on those occasional good nights I captured some of the finest images of nebulae and galaxies that I've ever managed from my backyard. The scope would obviously be a superb performer at a site with consistently good seeing.

Software Bisque's Paramount ME II

This is going to sound weird, but I wrote a detailed review of the Paramount ME II months before it was introduced in early 2013. Rather than being clairvoyant, I was actually writing about the company's Paramount MX (*S&T:* July 2012, p. 64). The ME II is a bigger, stronger, more robust version of the MX with a rated load capacity of 240 pounds (109 kg). Everything I said about the MX, with the obvious exceptions about its smaller physical stature, applies to the ME II. This is especially true of the ME II's pointing and tracking accuracy, and its extraordinary integration with Software Bisque's flagship *TheSkyX* program. Rather than repeat that material here, we've put a reprint of the earlier review on our website at **skypub.com/MX** (as this link is not publicly available, you'll need to manually enter it into your web browser).

Compared to the MX, there was nothing new I had to learn to set up and operate the ME II. Once everything was bolted in place and the RiDK 300 mounted on the ME II, it took only a few hours running routines in *TheSkyX* and its included *TPoint* software to achieve excellent polar alignment and all-sky pointing accuracy that was better than 13″. Furthermore, the tracking was good enough to make the unguided 10-minute first-light exposures with the RiDK 300 mentioned earlier.

Nevertheless, after that initial night setting up the ME II, the way I tested the mount was entirely different than how I handled the MX review. That's because I ran the ME II 100% remotely, although most of the time I was only a few hundred feet away working on a computer from the comfort of my home. But I also did a few tests connecting to the ME II with my office computer here in Cambridge, Massachusetts, and once, just for fun, with a netbook computer while relaxing at a hotel in Izmir, Turkey.

WHAT WE LIKE:

High load capacity

Exceptional pointing and tracking accuracy

Superb software integration for remote operation

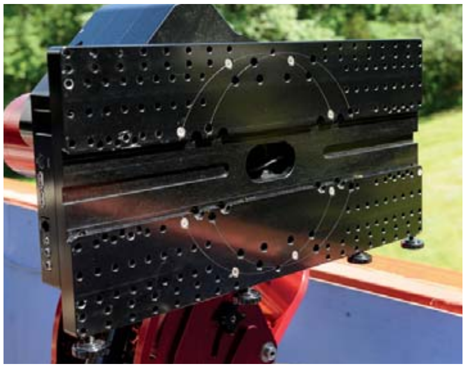
WHAT WE DON'T LIKE:

It would be nice to have more than two built-in USB ports on the saddle plate

Software Bisque wrote the book on operating telescope mounts remotely. The Paramount MX and ME II aren't just German equatorial mounts that had remote control added as an afterthought. They were designed from the ground up to be controlled remotely. And in my opinion, this is one of their greatest strengths.

In a nutshell, here's how I ran the system. A colleague loaned me a relatively modest laptop computer with a solid-state hard drive (SSD), which I loaded with *TheSkyX* and additional software for controlling my CCD cameras and the Rotofocuser. At the telescope, I routed power and USB 2.0 connections for the cameras and focuser through cables and connectors built into the Paramount, so only

At first glance, the Paramount ME II appears to be a twin of the smaller Paramount MX, but there are differences related to the ME II's far greater load capacity. Operation of the two mounts, however, is identical, and anyone familiar with using the MX will instantly know how to run the ME II.



Called the Versa-Plate, the ME II's equipment-mounting plate tested by the author includes a multitude of bolt holes as well as a Losmandy-style dovetail slot, making it very easy to attach just about anything to the mount.

one short USB cable ran between the mount and laptop. The computer also had a wired connection to my home network, which provided its link to the internet. The laptop remained on 24/7, and thanks in part to its SSD, the system worked flawlessly through our unusually cold New England winter.

I used an internet-controlled AC outlet to power the Paramount on and off, and a little bit of Rube Goldberg engineering let me open and close my observatory roof remotely. Lastly, I installed a low-light video camera in the observatory so that I could visually check on how things were running without me being physically present. I accessed the laptop controlling everything in the observatory from anyplace that had an internet connection. All that my "local" computer needed was conventional remote-desktop software that's designed to run one computer from another one when both are connected to the internet.

Everything worked beautifully, and to say that I was impressed with all of this is an understatement, especially given that this was my first experience doing all of my observing remotely. On dozens of nights spread across my months of testing, only once did I venture into the observatory to resolve a problem, and that was because a microswitch froze shut, preventing me from remotely closing the roof. This, by the way, is a potent reminder that any unattended facility needs failsafe backup on critical systems that affect the safety of expensive equipment.

Never once did I need to personally interact with the telescope or mount to resolve a problem. But that's not to say that everything worked perfectly. On a handful of occasions I had to reboot the remote computer, most likely due to conflicts between my software and stuff previously loaded on the machine by other users (and there was a lot of it!). Once or twice I also had to cycle power to the Paramount ME II to get it taking to the laptop again, but this too was likely because of issues with the computer. Thanks to an extremely accurate homing system built into the ME II, the mount always linked up perfectly with the sky overhead — the system never got lost.

I've tested a lot of equipment over the years, but I can't recall ever having a better experience than I had with the RiDK 300 and Paramount ME II. And given the sophistication of this setup, that says a lot. It truly is exceptional stuff. ✦

Sky & Telescope has published 55,638 pages since senior editor ***Dennis di Cicco*** *joined the staff in 1974.*

As with the image of M51 on page 38, the author set the focus of the RiDK 300 at the end of twilight and never tweaked it afterward on both nights when he made exposures for this view of the grand spiral galaxy M81 in Ursa Major. The 69 ten-minute LRGB exposures required more than 12 hours of observing time.

In This Section

Additional Observing Articles:

The intereacting galaxy pair Vorontsov-Velyaminov 323, also known as Arp 273, is discussed in detail on page 61.
NASA / ESA / HUBBLE HERITAGE TEAM (STSCI/AURA)

OBSERVING
Sky at a Glance

SEPTEMBER 2014

5 **DAWN:** Regulus shines less than 1° lower right of Venus low in the east a half hour before sunrise; as shown on page 48. Best in wide-field telescopes and binoculars.

17 **NIGHT**: Algol shines at minimum brightness for roughly two hours centered on 11:06 p.m. PDT.

20 **DAWN:** Jupiter shines upper left of the Moon.

NIGHT: Algol shines at minimum brightness for roughly two hours centered on 10:55 p.m. EDT (7:55 p.m. PDT); see page 53.

Sept 21 – Oct 6 **DAWN:** The zodiacal light is visible 120 to 80 minutes before sunrise from dark locations at mid-northern latitudes. Look for a huge pyramid of light stretching up through Jupiter.

22 **AUTUMN BEGINS** in the Northern Hemisphere at the equinox, 10:29 p.m. EDT.

24–30 **DUSK:** Mars passes less than 4° north of Antares. The planet is almost the same color as the star and just a little brighter. They appear closest (3.1°) on the 27th and 28th.

27 **DUSK:** The waxing crescent Moon floats just 1.5° to 3° lower right of Saturn (for North America).

28, 29 **DUSK:** The Moon floats to the right of Mars and Antares on the 28th and above them on the 29th, as shown on page 49.

Planet Visibility SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH

	◄SUNSET	MIDNIGHT	SUNRISE►
Mercury	W	Very low in sky, visible with binoculars	
Venus			E
Mars	SW		
Jupiter			NE E
Saturn	SW		

Moon Phases

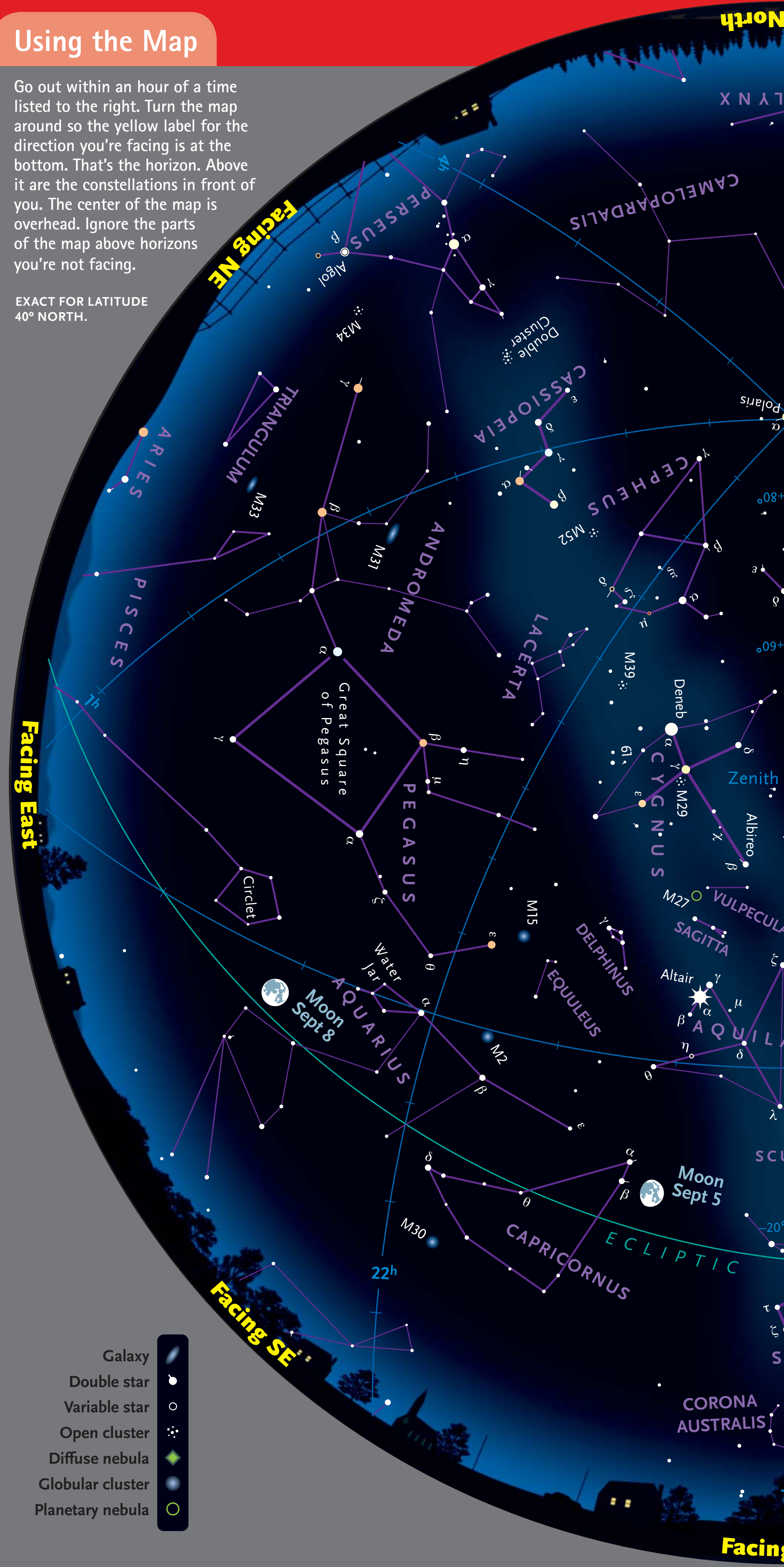
First Qtr Sept. 2 7:11 a.m. EDT
Full Sept. 8 9:38 p.m. EDT
Last Qtr Sept. 15 10:05 p.m. EDT
New Sept. 24 2:14 a.m. EDT

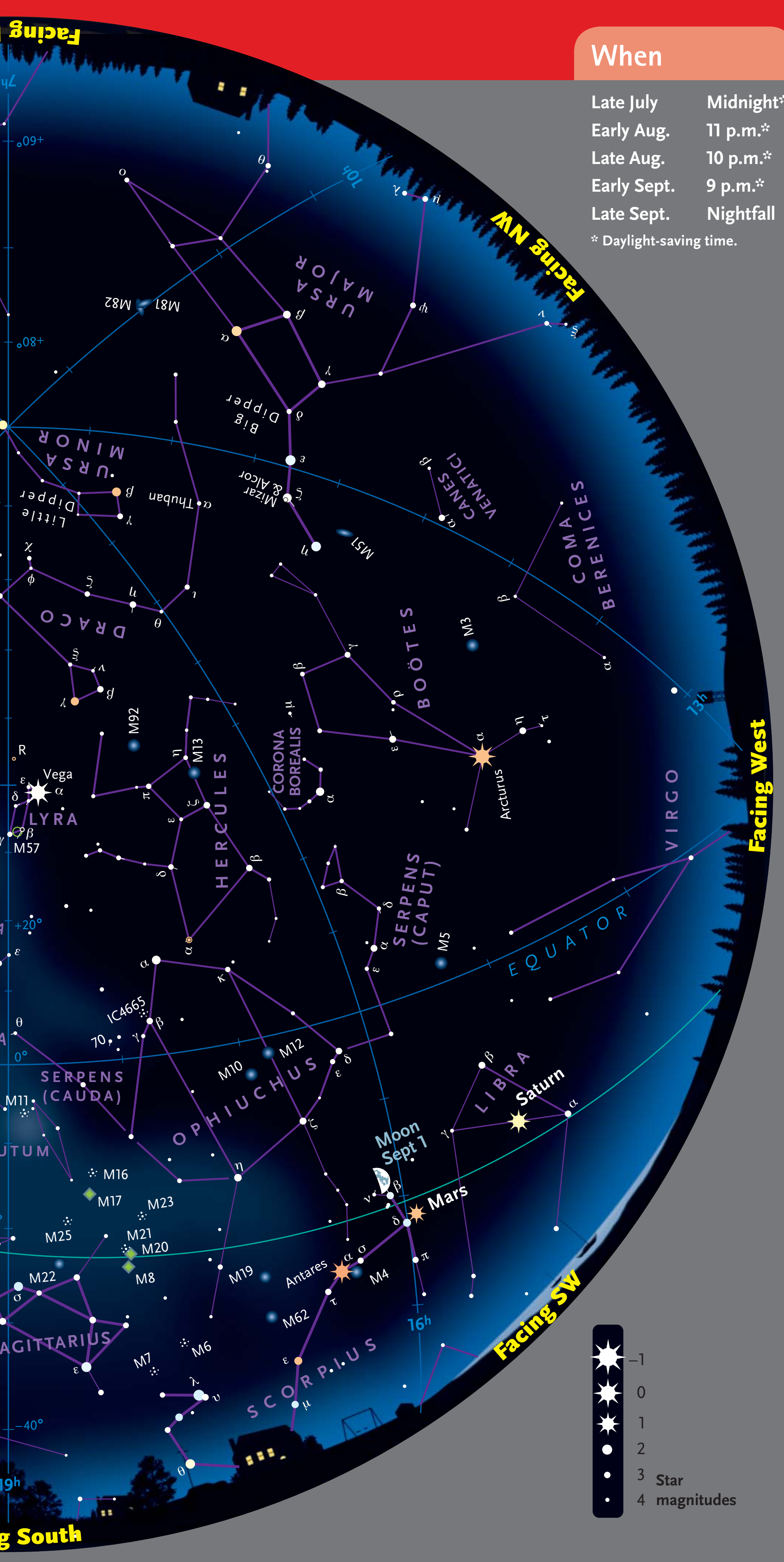
SUN	MON	TUE	WED	THU	FRI	SAT
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

Using the Map

Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. Above it are the constellations in front of you. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing.

EXACT FOR LATITUDE 40° NORTH.





When

Late July	Midnight*
Early Aug.	11 p.m.*
Late Aug.	10 p.m.*
Early Sept.	9 p.m.*
Late Sept.	Nightfall

* Daylight-saving time.

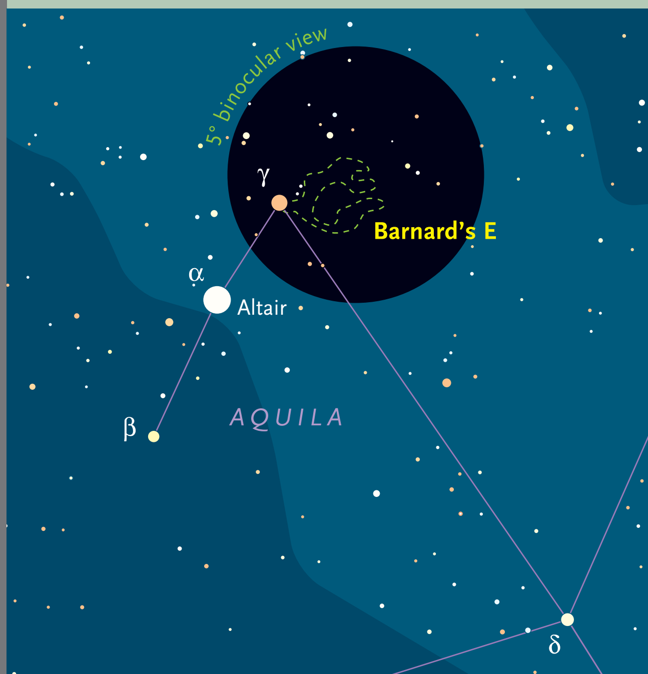
Gary Seronik

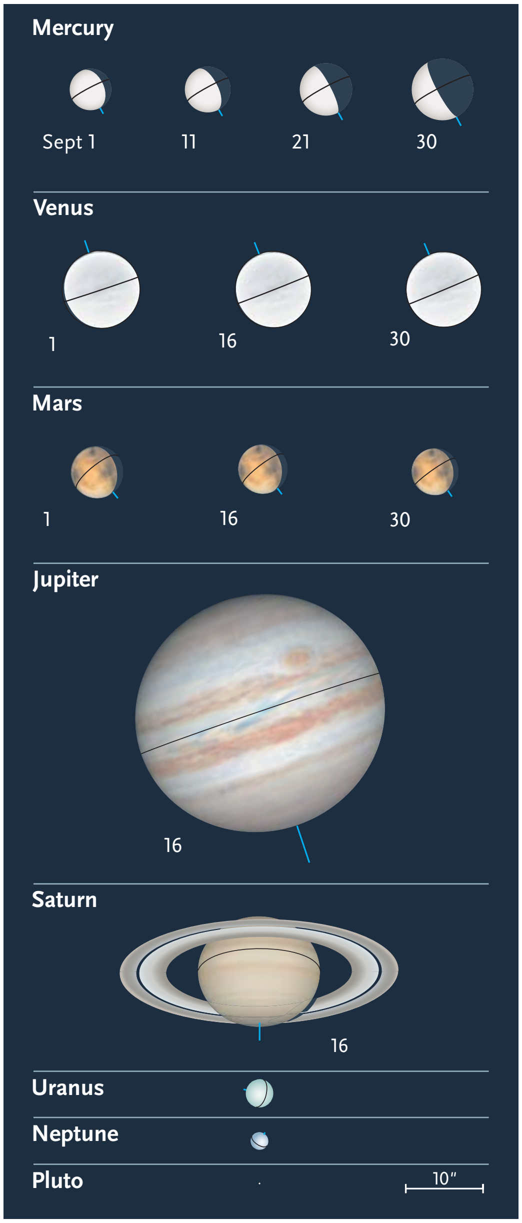
Aquila's Dark Secret

Dark nebulae are one class of deep-sky object that doesn't get enough attention. That's not surprising because appreciating them requires a different mindset. Instead of seeking light, you're hunting for the absence of luminosity. The other factor that works against dark nebulae is that you need very good skies to have any chance of seeing them at all. If you can't see the Milky Way easily, you're out of luck. That's because you need the background glow of starlight to render these opaque objects visible. Riding high in the sky this month, the constellation Aquila provides both a rich swath of Milky Way and one of the finest binocular dark nebulae.

The Charles Messier of dark nebulae was Edward Emerson Barnard. Like Messier, Barnard started out a comet hunter, but he's best known for his work at Yerkes Observatory, where he produced a photographic atlas of the Milky Way. A byproduct of this effort was his catalog of dark nebulae. Instead of M numbers, his objects have B numbers — including Aquila's B142 and B143. Together, these opaque clouds are also known as Barnard's E, owing to their photographic resemblance to the fifth letter of the alphabet.

I can make out Barnard's E fairly easily in my 10×30 image-stabilized binoculars, provided the skies are dark and clear. The E shape isn't distinct, however — the nebulae more resemble a pair of east-west elongated blobs joined by a vague vertical protrusion. I can see the dark nebula in my 15×45 image-stabilized binoculars too, but it's actually slightly more difficult. That's because the field of view is a bit too constricted to include both the nebula and enough of the surrounding Milky Way to let it stand out. ✦



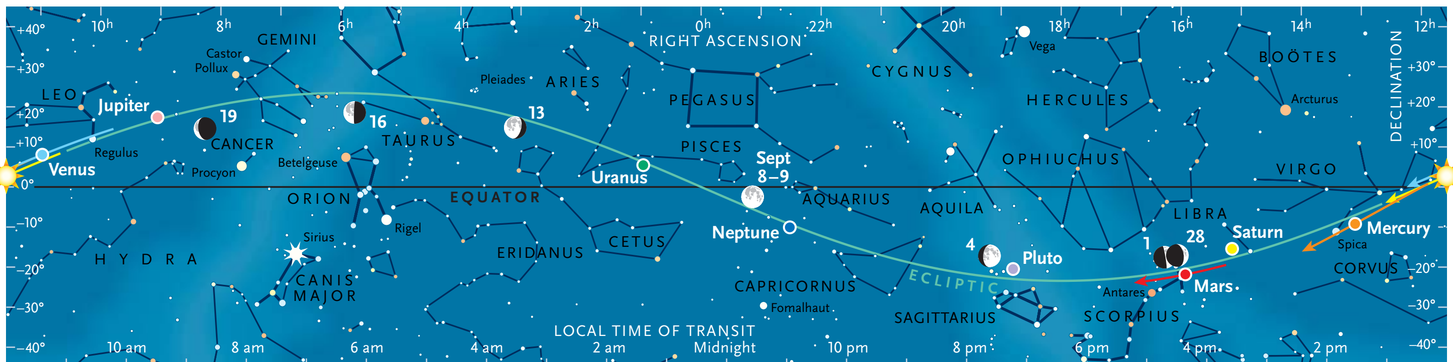


Sun and Planets, September 2014

	September	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$10^h\ 39.8^m$	+8° 27′	—	–26.8	31′ 42″	—	1.009
	30	$12^h\ 24.1^m$	–2° 36′	—	–26.8	31′ 56″	—	1.002
Mercury	1	$11^h\ 52.4^m$	+0° 54′	20° Ev	–0.2	5.4″	83%	1.247
	11	$12^h\ 43.0^m$	–6° 02′	24° Ev	0.0	5.9″	73%	1.133
	21	$13^h\ 24.9^m$	–11° 45′	26° Ev	0.0	6.8″	60%	0.990
	30	$13^h\ 50.2^m$	–15° 03′	25° Ev	+0.2	8.0″	42%	0.842
Venus	1	$9^h\ 46.6^m$	+14° 33′	14° Mo	–3.9	10.1″	97%	1.651
	11	$10^h\ 34.4^m$	+10° 24′	12° Mo	–3.9	10.0″	98%	1.675
	21	$11^h\ 20.9^m$	+5° 45′	9° Mo	–3.9	9.9″	99%	1.693
	30	$12^h\ 02.1^m$	+1° 20′	7° Mo	–3.9	9.8″	99%	1.705
Mars	1	$15^h\ 14.3^m$	–19° 24′	73° Ev	+0.6	6.8″	87%	1.374
	16	$15^h\ 55.0^m$	–21° 48′	68° Ev	+0.7	6.4″	88%	1.456
	30	$16^h\ 35.8^m$	–23° 32′	64° Ev	+0.8	6.1″	89%	1.529
Jupiter	1	$8^h\ 50.1^m$	+18° 12′	28° Mo	–1.8	32.1″	100%	6.147
	30	$9^h\ 12.7^m$	+16° 41′	51° Mo	–1.9	33.6″	99%	5.863
Saturn	1	$15^h\ 03.9^m$	–15° 08′	70° Ev	+0.6	16.2″	100%	10.239
	30	$15^h\ 13.3^m$	–15° 52′	44° Ev	+0.6	15.6″	100%	10.637
Uranus	16	$0^h\ 56.9^m$	+5° 19′	158° Mo	+5.7	3.7″	100%	19.081
Neptune	16	$22^h\ 30.4^m$	–10° 12′	163° Ev	+7.8	2.4″	100%	29.011
Pluto	16	$18^h\ 46.1^m$	–20° 35′	108° Ev	+14.1	0.1″	100%	32.402

The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial diameter.) Last are the percentage of a planet's disk illuminated by the Sun and the distance from Earth in astronomical units. (Based on the mean Earth–Sun distance, 1 a.u. is 149,597,871 kilometers, or 92,955,807 international miles.) For other dates, see SkyandTelescope.com/almanac.

Planet disks at left have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.



The Sun and planets are positioned for mid-September; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st, and an hour earlier at month's end.

Fred Schaaf *welcomes your comments at fschaaf@aol.com.*

Fred Schaaf

The Bird of the Starry Way

Cygnus is a source of endlessly varied delight.

How do you know but ev'ry Bird that cuts the airy way,
Is an immense world of delight, clos'd by your senses five?
— William Blake, *The Marriage of Heaven and Hell*

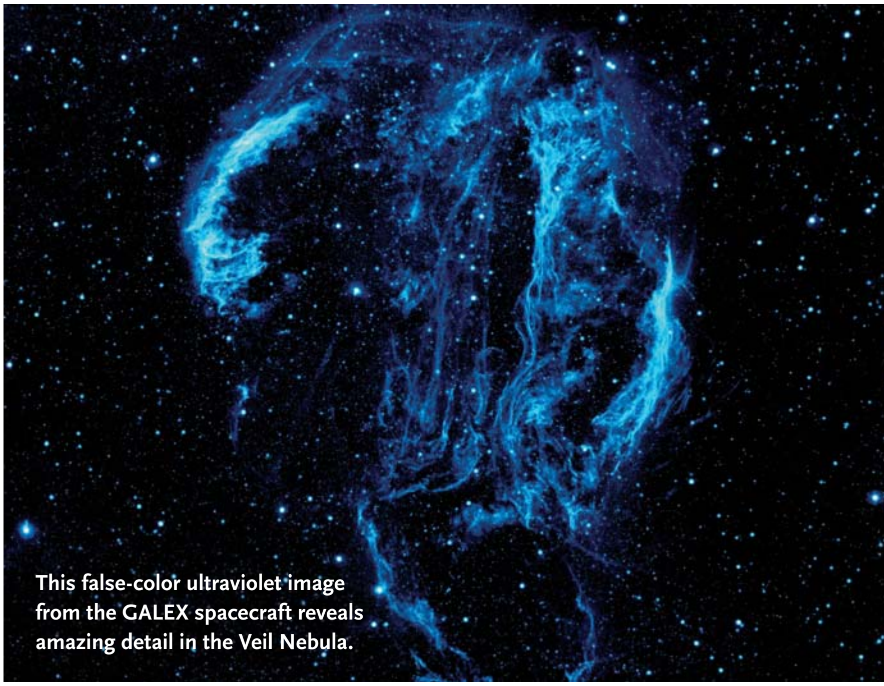
As summer ends, I know one bird that cuts not the airy but the starry way. Its name is Cygnus the Swan.

Aquila the Eagle has its attractions, rich little Lyra the Lyre has also been called the Swooping Vulture, and the sky contains a half dozen other bird constellations, both ancient and modern. But the wonders of Cygnus exceed all of them, both in number and variety. Cygnus is an immense world of delight for the sense of sight. Or rather, it is a multitude of magnificent worlds, each one different from the next.

Gloriously diverse Cygnus. What other constellation offers for the amateur telescope one of the sky's most dramatic supernova remnants (the Veil Nebula) and also one of its most vivid planetary nebulae (NGC 6826, the "Blinking Planetary")? But that's just the beginning. Cygnus also brings us a huge naked-eye emission nebula (the North America Nebula, described on page 56), which may be energized by the most luminous star within a few thousand light-years of Earth (Deneb).

The Veil Nebula itself is so diverse in its various sections that its components have been rewarded with a whole slew (or rather bouquet) of names: the Filamentary, Cirrus, Network, Lacework, and Bridal Veil nebulae. Parts of the Veil can be glimpsed through 10×50 binoculars in dark skies. At the other extreme, 16-inch telescopes may start showing you the Veil's colors, and structures that could spawn even more names. One section of the Veil reminds me of a luminous tornado.

The best of light and dark. Another aspect of Cygnus's diversity is the radiant Cygnus Star Cloud right next to the sky's largest chain of dark dust clouds. The Cygnus Star Cloud is a wreath of mist that the bird's straight neck shoots through, so bright and high in the sky from mid-northern latitudes that it's sometimes faintly visible even in urban or suburban skies where the limiting magnitude is 5.0 or worse. The Great Rift is the dark division that splits the Milky Way band in two all the way from Cygnus to far-southern Centaurus. Its interstellar dust begins not far from Deneb, in a region sometimes called the Northern Coalsack — named after the smaller but more intense Coalsack in the far-southern sky. Appropriately, the



NASA / JPL-CALTECH

This false-color ultraviolet image from the GALEX spacecraft reveals amazing detail in the Veil Nebula.

true Coalsack is adjacent to the Southern Cross, and the Northern Coalsack lies next to the Northern Cross, which is formed from the Swan's five brightest stars.

A bird that cuts the Milky Way. The Rift cuts longitudinally *down* the Milky Way's luminous band, but the great dust cloud called Le Gentil 3 cleaves most of the way *across* the Milky Way northeast of Deneb.

Another thing that cuts across the Milky Way — almost completely — is the chain of stars that forms Cygnus's full wingspan. Cygnus can be said to be in several different kinds of flight. Its main pattern, the Swan, appears to fly almost directly down the Milky Way band — that is, to the southwest (appropriate in this season when birds are migrating south at northern and mid-northern latitudes). But when we stare at Cygnus's more distant stars — especially those of the glorious Cygnus Star Cloud — we're looking ahead in the direction that our part of the galaxy rotates. Our local neighborhood of stars is flying more or less toward these distant reaches of Cygnus, while Cygnus's stars fly on ahead.

Our personal flight with Cygnus is not over yet. Next month here we'll explore many more of the diversities and motions of the starry sky's most wondrous bird. ✦

Mars Meets Its Rival

The Red Planet has a fine conjunction with Antares this month.

Mars and Saturn shine low in the southwest early on September evenings. Mars remains at almost the same altitude all month, but Saturn descends a little lower into the sunset each evening. Then late in the month Mars has a fine conjunction with similarly colored Antares. And Mercury may be visible at dusk through telescopes and binoculars.

The other two bright planets shine in the east at dawn: Jupiter high and climbing, Venus very low and sinking.

DUSK

Mercury has its worst evening apparition of 2014 for mid-northern latitudes — visible only with optical aid shortly after sunset. It's at greatest elongation (26° east of the Sun) on September 21st, but it appears very low in the west for northern observers due to the shallow angle that the ecliptic makes with the horizon at dusk at this time of year.

Conversely, this is Mercury's best evening apparition of the year from the Southern Hemisphere, where the ecliptic is as close to vertical as it ever can be as the Sun's glow fades.

For an interesting observing challenge, go to a spot with a completely unobstructed western horizon before sunset on September 20th. Note the spot where the Sun disappears, and then start scanning with a telescope or binoculars 25° left of that point and 5° to 10° above the horizon for zero-magnitude Mercury. Then look carefully for 1.0-magnitude Spica just 0.6° to Mercury's right.

EARLY EVENING

Saturn begins September less than 6° to the right of identically bright Mars, but the gap between them widens rapidly as Mars races eastward relative to the background stars. Saturn is moving eastward too, though much more slowly, so its separation from Alpha Librae (Zubenelgenubi) increases slightly. The ringed planet maintains its magnitude of +0.6, and its rings now open to more than 23° from edge-on. But Saturn stands only about 20° high in the southwest an hour after sunset at the start of the month and about 10° high an hour after sunset at month's end. The interval between sunset and Saturnset decreases from about 3 to 2 hours during September.

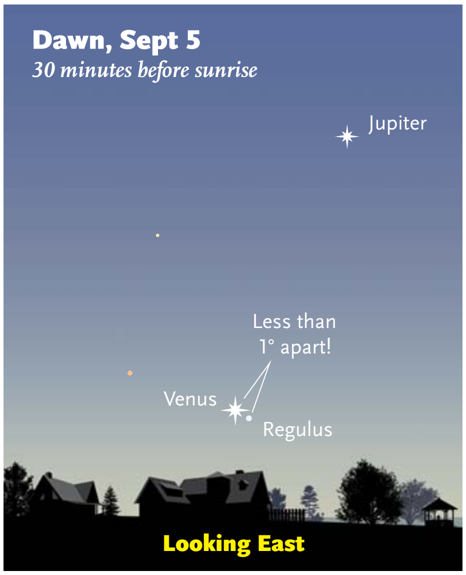
Mars dims a trace from magnitude +0.6 to +0.8 in September, and its disk shrinks from 6.8″ to 6.1″ across — too small to show significant detail through most telescopes. However, Mars does make an interesting trek out of Libra, through the "fence" of stars marking the head of Scorpius, and ends the month just a few degrees from slightly fainter Antares.

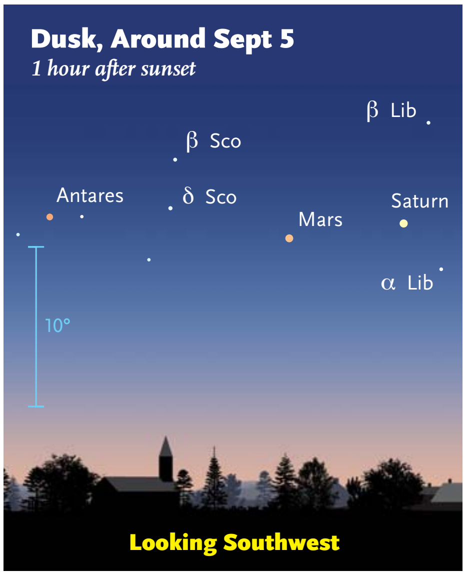
This month, Mars's swift movement eastward relative to the stars almost keeps pace with the Sun's. So Mars sets just about 3 hours after sunset all month. Mars appears halfway between Saturn and Antares on September 12th. On the 17th Mars glides just ½° north of the fascinating 2nd-magnitude variable star Delta Scorpii (Dschubba). The other stars in Scorpius's head (including the bright double Beta Scorpii and the naked-eye Omega pair) also make for a pretty scene with Mars around this date.

But the most interesting and attractive event in Mars's September journey is its passage north of Antares, the "rival of Mars" in color. Mars is 1½° south of the ecliptic now, so it passes just 3.1° north of slightly dimmer Antares on September 27th and 28th. Compare the hues of the planet and star with naked eye and binoculars. Which seems redder — or at least a deeper orange-gold?

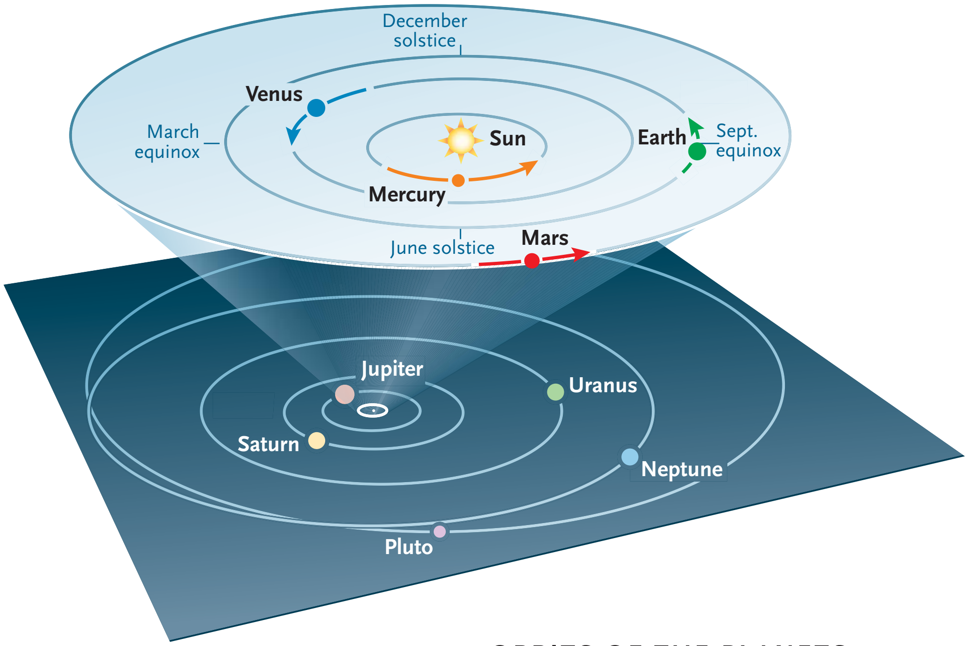
Next month Mars will have a very close encounter in space with Comet C/2013 A1 Siding Spring.

Dim **Pluto** is highest (though not very high) in Sagittarius as darkness falls, and it sets in the middle of the night. See page 50 of the June issue if you wish to seek it.





Fred Schaaf



LATE NIGHT TO DAWN

Neptune was at opposition on August 29th, and **Uranus** will be on October 7th. So both of these pale giants are up most of the night. See page 50 for finder charts.

DAWN

Jupiter engaged in a marvelous close conjunction with Venus back on August 18th. But now the enormous planet is coming up sooner and sooner before Venus and the Sun. The interval between Jupiter-rise and sunrise increases from 2½ to 4½ hours this month. Jupiter brightens marginally from –1.8 to –1.9 in September but remains near its minimum apparent size. It moves eastward away from M44 (the Beehive Cluster), approaching the western boundary of Leo by month's end.

Venus rises only an hour before the Sun as September begins, and a half-hour before as the month closes. Look for it down near the east horizon far below Jupiter. Optical aid should reveal Regulus less than 1° from Venus on September 5th. Venus is very low in bright twilight at month's end and will reach superior conjunction with the Sun on October 25th.

SUN AND MOON

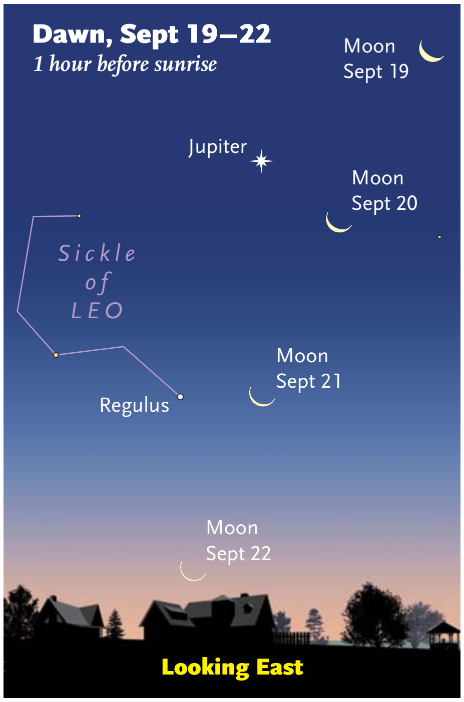
The **Sun** reaches the equinox on 10:29 p.m. EDT on September 22nd, starting autumn in the Northern Hemisphere and spring in the Southern Hemisphere.

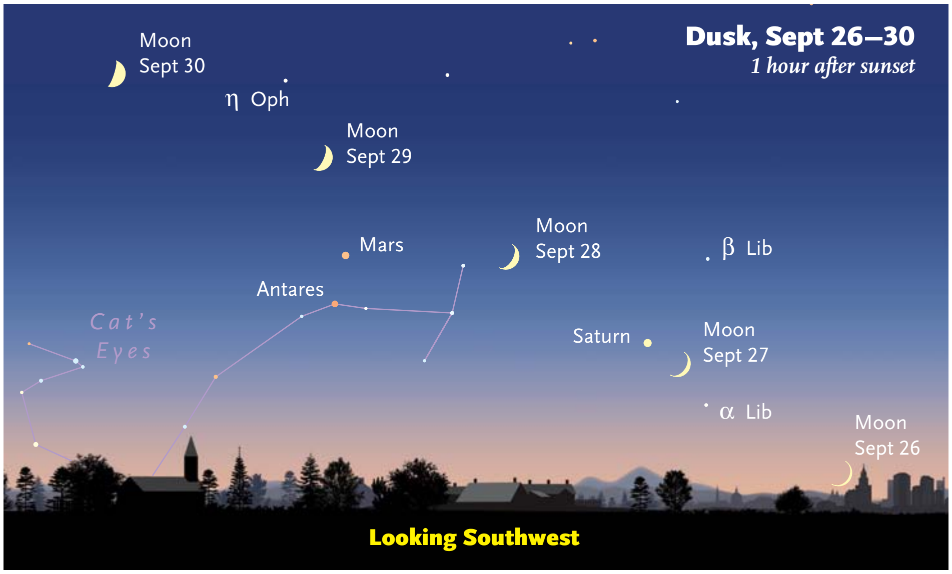
The **Moon** is a waning crescent lower right of Jupiter on the morning of September 20th, and right of Regulus on the 21st.

ORBITS OF THE PLANETS

The curved arrows show each planet's movement during September. The outer planets don't change position enough in a month to notice at this scale.

Back in the evening sky, the waxing lunar crescent shines lower right of Saturn on September 27th and above Mars and Antares on the 29th. ✦

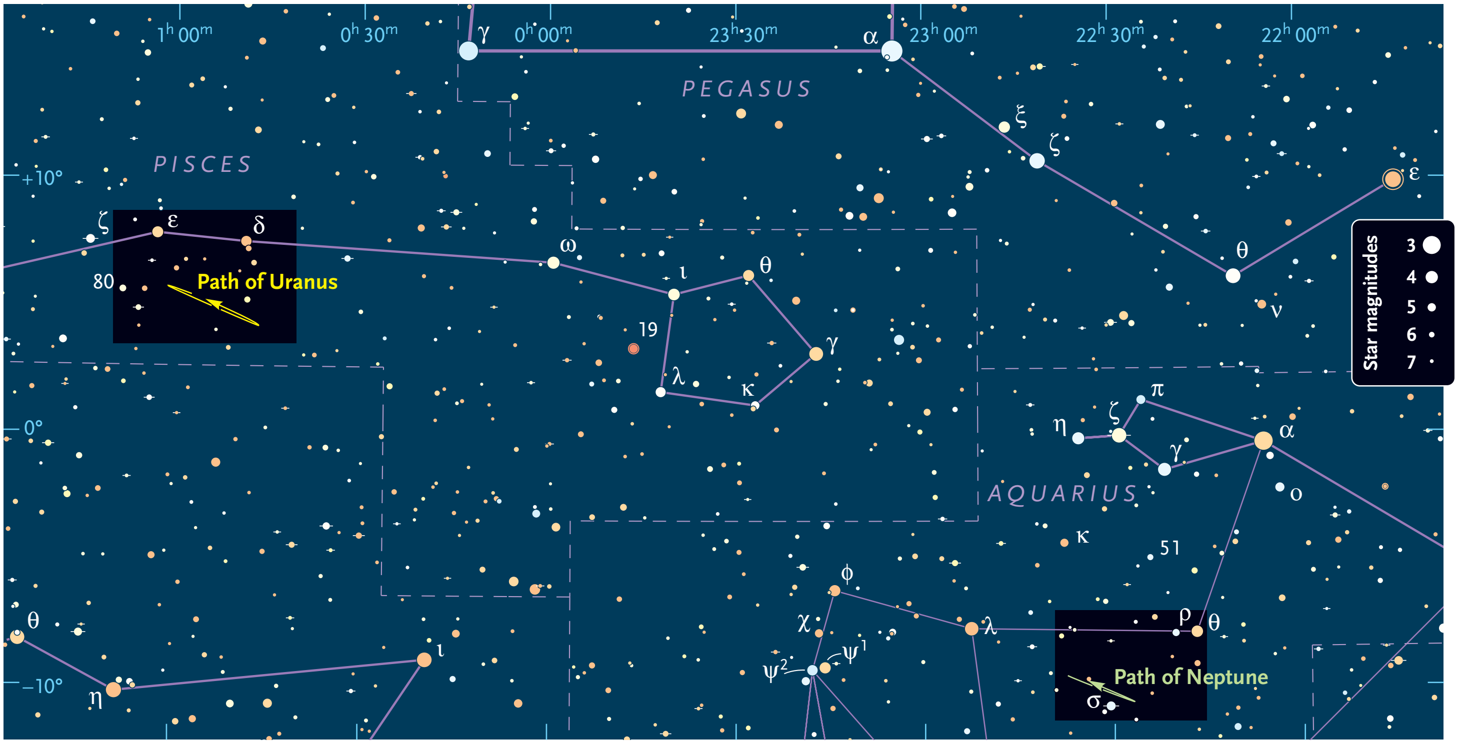




These scenes are drawn for near the middle of North America (for latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date. The blue 10° scale bar is about the width of your fist at arm's length. For clarity, the Moon is shown three times its actual apparent size.

Ice-Giant Spotting

Uranus and Neptune are in reach of binoculars as they go their separate ways.



If you came into amateur astronomy later than 1975, you've never known Uranus and Neptune to be as far apart as they are now: 40°. For decades, it seemed like the twin outer planets were naturally twinned on the sky as well. And among those who were around at the time, who can forget their pairing in 1993, when they fit into the same low-power view just 1.1° apart?

Those times aren't coming back until the 22nd century. Uranus, in its faster orbit, is pulling ever farther eastward away from Neptune. Pretty soon we'll have to stop including them in the same annual wide-field finder chart like the one above.

The black rectangles show the areas of the deeper close-up charts, with date ticks, on the facing page.

Saturn's Rhea to Occult a Star

An unusual event happens early on the evening of September 12th for telescope users in North America. Saturn's second-largest satellite, 10.2-magnitude Rhea, will occult a 7.8-magnitude star.

The occultation will be visible from much of the northeastern United States and Ontario. Observers south of there will see a very near miss, and watchers in the west will find the star moving away from Rhea by the time darkness falls.

You'll need a good view low to the southwest; Saturn and its retinue will be sinking toward the horizon during and after twilight. Saturn is the right-hand point in a roughly horizontal row of three, Mars is in the middle, and Antares is on the left.

The occultation happens around 8:38 p.m. Eastern Daylight Time; 7:38 p.m. CDT. The farther east you are, the lower Saturn will be. The farther west, the more likely the event will occur while the sky is still too bright. By the time darkness arrives on the West Coast, Rhea and the star (SAO 159034) will be well separated.

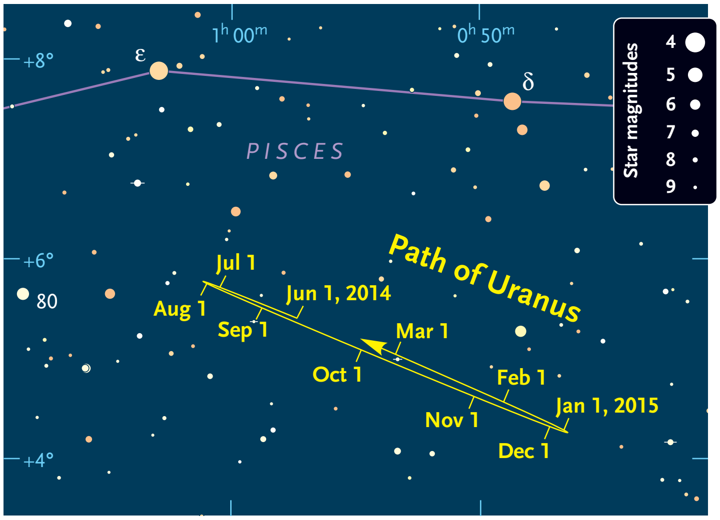
The second-brightest point in the immediate field of view will

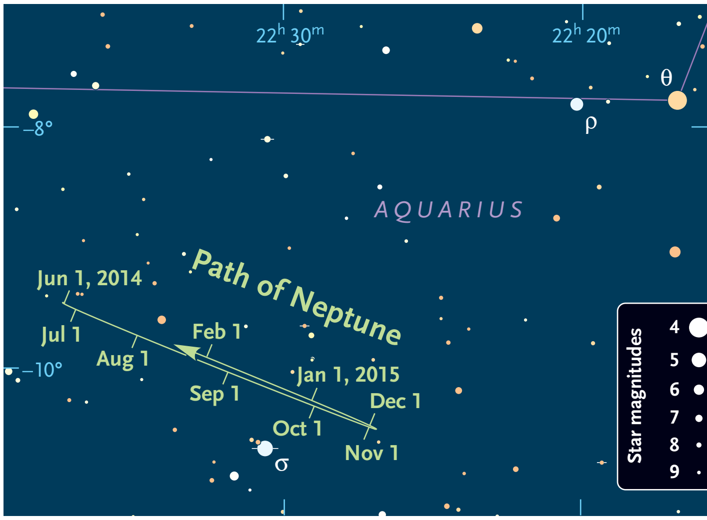
Uranus spends the rest of this year at about magnitude 5.7, making it a piece of cake to spot in binoculars once you locate its position. Neptune is more challenging in binoculars at about magnitude 7.8.

In a telescope at high power, both show tiny, fuzzy, nonstellar disks. Uranus is currently 3.7″ wide; Neptune is 2.4″. In my 6- and 12.5-inch scopes, I pretty consistently see a trace of aquamarine blue-green in Uranus's pale light. Neptune looks duskier gray with a just a hint of blue. Long-term photometry at Lowell Observatory has shown that their colors shift slightly from time to time. For more on their sometimes controversial colors, see the September 2010 issue, page 56.

Unique in the solar system, these two intermediate-mass planets consist mostly of volatile hydrogen compounds: water (OH_2), ammonia (NH_3), and methane (CH_4) — as opposed to the rock and iron of the terrestrial planets and the hydrogen and helium of Jupiter and Saturn. Planetary scientists call these and certain other volatile compounds (such as CO_2 and CO) "ices" — even if they only turn solid in unearthly cold, and even though they're actually fluids at the high temperatures and pressures of deep planetary interiors. Uranus and Neptune are thus called the solar system's "ice giants."

Another thing Uranus and Neptune have in common is that they're the solar system's only major planets (by the current definition) that were discovered rather than always being obvious. William Herschel in England swept up Uranus by accident in 1781 while using a homemade reflector in his back garden. Johann Galle at Berlin Observatory discovered Neptune in a very deliberate search in 1846, after Urbain Le Verrier predicted its position from unexplained gravitational tugs on Uranus.





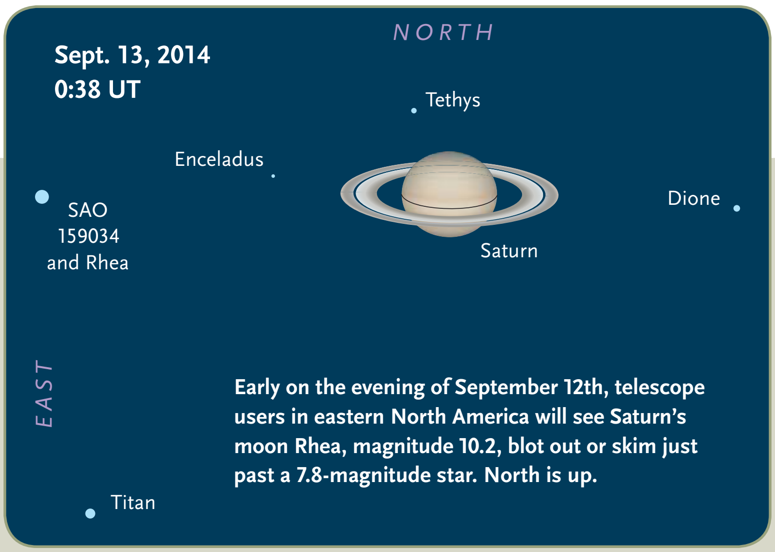
Facing page: **South of the Great Square of Pegasus, 6th-magnitude Uranus and 8th-magnitude Neptune mosey through their little retrograde loops. Neptune is at opposition on August 29th, Uranus on October 7th. The closeup charts on this page pinpoint their locations among fainter stars. Track their motion!**

be Titan, magnitude 8.9 and farther south as shown at right.

Where the occultation happens, the combined light of Rhea and the star (they'll have merged into one blended image in a telescope) will drop by 2.5 magnitudes. That's a dramatic, factor-of-10 decrease in brightness.

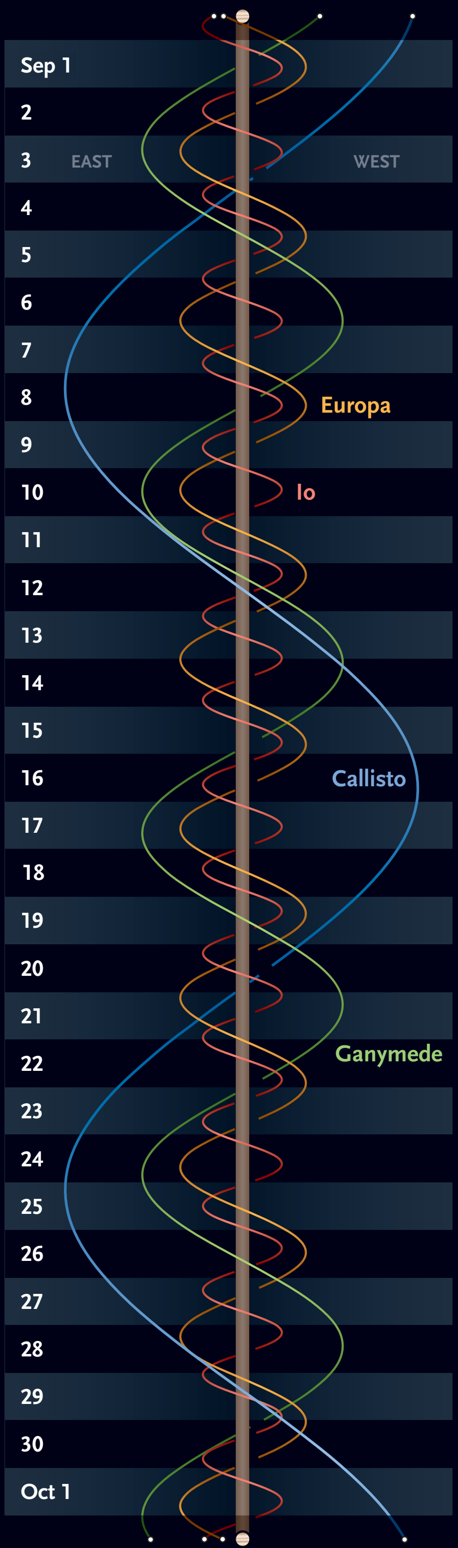
The occultation will last for up to 58 seconds, depending on how close you are to the midline of the shadow path.

There's no particular scientific gain to be had from timing this occultation, since Rhea's size, shape, and orbit have been refined to exquisite precision from 10 years of observations by NASA's Cassini spacecraft orbiting Saturn. But it will certainly be interesting to watch and perhaps videorecord.



Early on the evening of September 12th, telescope users in eastern North America will see Saturn's moon Rhea, magnitude 10.2, blot out or skim just past a 7.8-magnitude star. North is up.

S&T: LEAH TISCIONE



The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites' positions east or west of Jupiter.

The Return of Jupiter

In September you'll find Jupiter climbing the eastern sky by the beginning of dawn, shining in dim Cancer in the early stage of its 13-month apparition across the night sky from dawn to dusk.

As dawn brightens, the telescopic seeing often quiets down and high-power views may become very sharp. Jupiter is still on the far side of the Sun and nearly as small as we ever see it, 32″ to 33″ across its fat equator. But it has been out of good view since June. What have its markings been doing in the meantime?

When we left off as Jupiter sank toward the sunset, the North Equatorial Belt had become narrower and slightly darker red-brown than the South Equatorial Belt, as seen on this page. The two great belts may be all that most amateur telescopes show on Jupiter at the beginning of this apparition. Have they changed since you last looked?

Any telescope shows Jupiter's four large moons: Io, Europa, Ganymede, and Callisto. Binoculars usually reveal at least two or three, occasionally all four. Identify them at any date and time in September with the diagram at left.

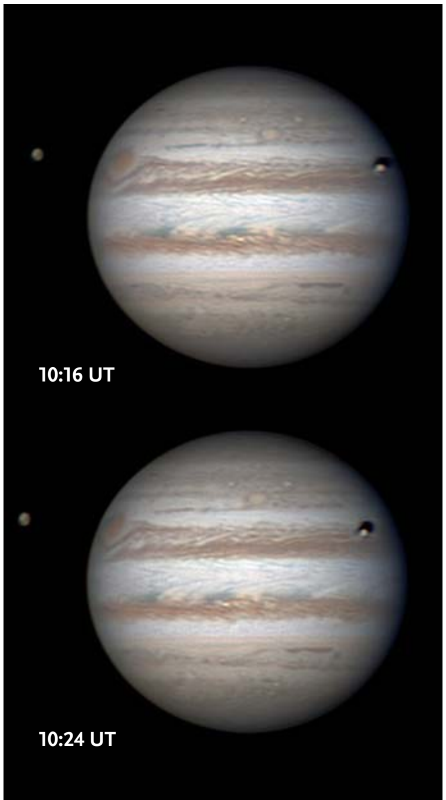
Interactions between Jupiter and its satellites are listed on the facing page.

Jupiter's Great Red Spot is becoming shorter and rounder with each passing decade (July issue, page 16). This month the Red Spot is a tough catch, with Jupiter far away and not very high. A lot will depend on how light or dark the spot may have become. Here are the times, in Universal Time, when it should cross Jupiter's central meridian. The dates, also in UT, are in bold:

September 1, 5:32, 15:28; **2**, 1:23, 11:19, 21:15; **3**, 7:11, 17:06; **4**, 3:02, 12:58, 22:54; **5**, 8:50, 18:45; **6**, 4:41, 14:37; **7**, 0:33, 10:29, 20:24; **8**, 6:20, 16:16; **9**, 2:12, 12:07, 22:03; **10**, 7:59, 17:55; **11**, 3:51, 13:46, 23:42; **12**, 9:38, 19:34; **13**, 5:30, 15:25; **14**, 1:21, 11:17, 21:13; **15**, 7:08, 17:04; **16**, 3:00, 12:56, 22:52; **17**, 8:47, 18:43; **18**, 4:39, 14:35; **19**, 0:30, 10:26, 20:22; **20**, 6:18, 16:13; **21**, 2:09, 12:05, 22:01; **22**, 7:57, 17:52; **23**, 3:48, 13:44, 23:40; **24**, 9:35, 19:31; **25**, 5:27, 15:23; **26**, 1:18, 11:14, 21:10; **27**, 7:06, 17:01; **28**, 2:57, 12:53, 22:49; **29**, 8:44, 18:40; **30**, 4:36, 14:32.

These times assume that the spot is centered at System II longitude 223°. If it's not following predictions, it will transit 1⅔ minutes early for every degree of longitude less than 223°, or 1⅔ minutes later for every degree greater than 223°.

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. A light blue or green filter slightly boosts the contrast of Jupiter's reddish, orange, and tan markings.



In these unusual scenes, which Christopher Go took on May 20th eight minutes apart, bright Io is smack in front of the larger shadow of Ganymede. Ganymede itself is at left with its disk resolved. South is up.

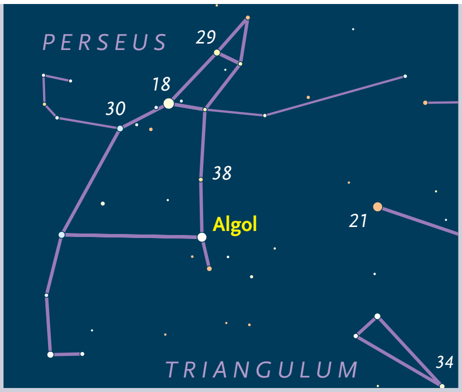
Big Full Moons

The full Moons of August and September are *perigean*, meaning the Moon turns full near the date when it's at perigee, closest to Earth for the month. Perigean "supermoons," however, are only a *little bit* super. They appear no more than 7% wider than the Moon does on average, or 14% wider than the "mini-moons" at the monthly apogees.

The full Moon on August 10th is the largest of the year. The one on the night of September 8th matches it to within a half percent.

The Moon's perigee point moves around the celestial sphere in about 8.85 years (due to perturbations by the Sun). So each year, the season of perigean full Moons begins about 1½ months later, on average, than it did the year before. ✦

Minima of Algol



Algol, the prototype eclipsing variable star, fades every 2.87 days from its usual 2.1 magnitude to 3.4. It stays near minimum light for two hours, and takes several more hours to fade and to rebrighten. Shown above are magnitudes of comparison stars with decimal points omitted. (These geocentric predictions are from the heliocentric elements Min. = JD 2452253.559 + 2.867362*E*, where *E* is any integer. Courtesy Gerry Samolyk, AAVSO.)

Aug.	UT	Sept.	UT
3	9:08	1	1:14
6	5:57	3	22:03
9	2:45	6	18:52
11	23:34	9	15:40
14	20:23	12	12:29
17	17:11	15	9:18
20	14:00	18	6:06
23	10:49	21	2:55
26	7:37	23	23:44
29	4:26	26	20:32
		29	17:21

Phenomena of Jupiter's Moons, September 2014

Date	UT	Event
Sept. 1	1:52	I.Sh.I
	2:29	I.Tr.I
	4:10	I.Sh.E
	4:46	I.Tr.E
	7:49	III.Ec.D
	13:56	III.Oc.R
	23:00	I.Ec.D
Sept. 2	1:55	I.Oc.R
	8:27	II.Ec.D
	12:35	II.Oc.R
	20:21	I.Sh.I
	20:59	I.Tr.I
	22:38	I.Sh.E
	23:16	I.Tr.E
Sept. 3	16:51	IV.Ec.D
	17:28	I.Ec.D
	20:25	I.Oc.R
	21:35	IV.Ec.R
	23:07	IV.Oc.D
Sept. 4	2:37	II.Sh.I
	3:55	IV.Oc.R
	3:56	II.Tr.I
	5:27	II.Sh.E
	6:46	II.Tr.E
	14:49	I.Sh.I
	15:29	I.Tr.I
	17:07	I.Sh.E
	17:46	I.Tr.E
	21:56	III.Sh.I
Sept. 5	0:37	III.Tr.I
	1:28	III.Sh.E
	4:12	III.Tr.E
	11:56	I.Ec.D
	14:55	I.Oc.R
	21:45	II.Ec.D
Sept. 6	1:59	II.Oc.R
	9:18	I.Sh.I
	9:59	I.Tr.I
	11:35	I.Sh.E
	12:16	I.Tr.E
Sept. 7	6:25	I.Ec.D
	9:25	I.Oc.R
	15:54	II.Sh.I
	17:19	II.Tr.I
	18:44	II.Sh.E
	20:10	II.Tr.E
Sept. 8	3:46	I.Sh.I
	4:29	I.Tr.I
	6:03	I.Sh.E
	6:46	I.Tr.E
	11:47	III.Ec.D
	18:20	III.Oc.R
Sept. 9	0:53	I.Ec.D
	3:55	I.Oc.R
	11:02	II.Ec.D
	15:22	II.Oc.R
	22:15	I.Sh.I
	22:59	I.Tr.I
Sept. 10	0:32	I.Sh.E
	1:16	I.Tr.E
	19:22	I.Ec.D
	22:25	I.Oc.R
Sept. 11	5:12	II.Sh.I
	6:43	II.Tr.I
	8:02	II.Sh.E
	9:34	II.Tr.E
	16:43	I.Sh.I
	17:29	I.Tr.I
	19:00	I.Sh.E
	19:46	I.Tr.E
Sept. 12	1:54	III.Sh.I
	3:27	IV.Sh.I
	4:59	III.Tr.I
	5:26	III.Sh.E
	8:08	IV.Sh.E
	8:34	III.Tr.E
	10:43	IV.Tr.I
	13:50	I.Ec.D
	15:29	IV.Tr.E
	16:55	I.Oc.R
Sept. 13	0:20	II.Ec.D
	4:46	II.Oc.R
	11:12	I.Sh.I
	11:59	I.Tr.I
	13:29	I.Sh.E
	14:16	I.Tr.E
Sept. 14	8:18	I.Ec.D
	11:25	I.Oc.R
	18:29	II.Sh.I
	20:06	II.Tr.I
	21:19	II.Sh.E
	22:57	II.Tr.E
Sept. 15	5:40	I.Sh.I
	6:28	I.Tr.I
	7:57	I.Sh.E
	8:46	I.Tr.E
	15:46	III.Ec.D
	22:44	III.Oc.R
Sept. 16	2:47	I.Ec.D
	5:55	I.Oc.R
	13:37	II.Ec.D
	18:09	II.Oc.R
Sept. 17	0:09	I.Sh.I
	0:58	I.Tr.I
	2:26	I.Sh.E
	3:16	I.Tr.E
	21:15	I.Ec.D
Sept. 18	0:25	I.Oc.R
	7:47	II.Sh.I
	9:29	II.Tr.I
	10:37	II.Sh.E
	12:20	II.Tr.E
	18:37	I.Sh.I
	19:28	I.Tr.I
	20:54	I.Sh.E
	21:45	I.Tr.E
Sept. 19	5:51	III.Sh.I
	9:20	III.Tr.I
	9:24	III.Sh.E
	12:56	III.Tr.E
	15:44	I.Ec.D
	18:54	I.Oc.R
Sept. 20	2:54	II.Ec.D
	7:32	II.Oc.R
	10:51	IV.Ec.D
	13:05	I.Sh.I
	13:58	I.Tr.I
	15:22	I.Sh.E
	15:37	IV.Ec.R
	16:15	I.Tr.E
	19:19	IV.Oc.D
Sept. 21	0:11	IV.Oc.R
	10:12	I.Ec.D
	13:24	I.Oc.R
	21:04	II.Sh.I
	22:52	II.Tr.I
	23:54	II.Sh.E
Sept. 22	1:43	II.Tr.E
	7:34	I.Sh.I
	8:28	I.Tr.I
	9:51	I.Sh.E
	10:45	I.Tr.E
	19:44	III.Ec.D
	23:20	III.Ec.R
	23:27	III.Oc.D
Sept. 23	3:05	III.Oc.R
	4:41	I.Ec.D
	7:54	I.Oc.R
	16:12	II.Ec.D
	20:55	II.Oc.R
Sept. 24	2:02	I.Sh.I
	2:57	I.Tr.I
	4:19	I.Sh.E
	5:14	I.Tr.E
	23:09	I.Ec.D
Sept. 25	2:24	I.Oc.R
	10:22	II.Sh.I
	12:15	II.Tr.I
	13:12	II.Sh.E
	15:06	II.Tr.E
	20:31	I.Sh.I
	21:27	I.Tr.I
	22:48	I.Sh.E
	23:44	I.Tr.E
Sept. 26	9:50	III.Sh.I
	13:23	III.Sh.E
	13:40	III.Tr.I
	17:15	III.Tr.E
	17:37	I.Ec.D
	20:53	I.Oc.R
Sept. 27	5:29	II.Ec.D
	10:17	II.Oc.R
	14:59	I.Sh.I
	15:57	I.Tr.I
	17:16	I.Sh.E
	18:14	I.Tr.E
Sept. 28	12:06	I.Ec.D
	15:23	I.Oc.R
	21:27	IV.Sh.I
	23:39	II.Sh.I
Sept. 29	1:37	II.Tr.I
	2:09	IV.Sh.E
	2:29	II.Sh.E
	4:29	II.Tr.E
	6:40	IV.Tr.I
	9:28	I.Sh.I
	10:26	I.Tr.I
	11:28	IV.Tr.E
	11:44	I.Sh.E
	12:43	I.Tr.E
	23:43	III.Ec.D
Sept. 30	3:18	III.Ec.R
	3:45	III.Oc.D
	6:34	I.Ec.D
	7:24	III.Oc.R
	9:53	I.Oc.R
	18:46	II.Ec.D
	23:39	II.Oc.R

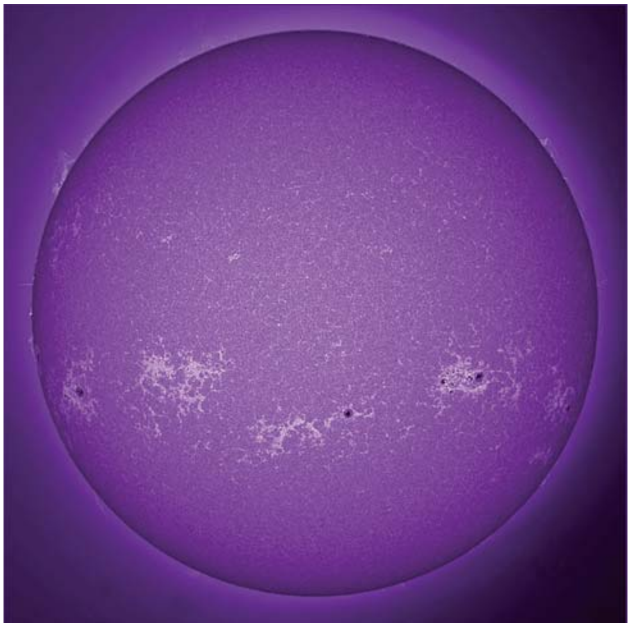
Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 4 hours ahead of Eastern Daylight Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

The Violet Sun

A K-line filter can reveal solar activity normally hidden from view.

The Sun in calcium-K (Ca-K) light offers the most amazing display of solar details and activity that you may never see in an eyepiece. You read that right: the Ca-K band at 393.3 nanometers lies so close to the ultraviolet that many observers see little more than a dim violet disk through a Ca-K filter. This is why you'll rarely see observers looking through Ca-K telescopes alongside the more common hydrogen-alpha scopes. But the details are there, ranging from sunspots and the bright plages that outline spots' surrounding magnetic fields, to solar flares, explosive magnetic reconnection events, and even the brighter solar prominences. These details can change in a short time frame and reveal a dynamic Sun that — with the aid of a video camera and monitor — is in fact visible to everybody.

The region of the Sun seen in Ca-K resides in the chromosphere, about 500 to 2,000 kilometers (300 to 1,200 miles) above the photosphere, which we often call the Sun's "visible surface" and is the layer we see in white light. Sunspots in Ca-K appear very similar to how they look in white light, displaying details of the umbral and penumbral regions. These spots are surrounded by bright plages, emission regions that coincide with (and closely resemble) the bright photospheric faculae usually seen foreshortened near the solar limb in white light. But these plages are much brighter in Ca-K compared to faculae, and you can see them clearly anywhere on the solar disk at this narrow wavelength.



HOWARD ESKILDSEN

Although difficult for some observers to see, the Sun in one of the emission lines of ionized calcium (Ca-K) offers the best of both white-light and Hα views: dark sunspots, bright plages, and rapidly evolving prominences along the solar limb.

The plages are emission regions tied to strong magnetic fields and are nearly identical to the shape of the magnetic regions visible on solar magnetograms. When several spot groups, or *active regions*, lie very close together you might have difficulty in white light telling which spots are in which regions. In Ca-K, the plages may make it easier to determine to which active region the spots belong.

Although all sunspots reside on the photosphere beneath a plage, many plages develop without any associated spots. Plages form before spots become visible and persist long after the spots have faded away, if the spots form at all. You can identify some plages several solar rotations after their spots have disappeared. Even when there are very few spots on the Sun, it's exciting to observe bright plages as they burst into view, expand, and mature over days to weeks, and then slowly spread apart and diffuse into the bright, web-like network of the chromosphere. Sometimes new plages emerge within an old fading plage, making it difficult to tell where the old plage ends and the new one begins.

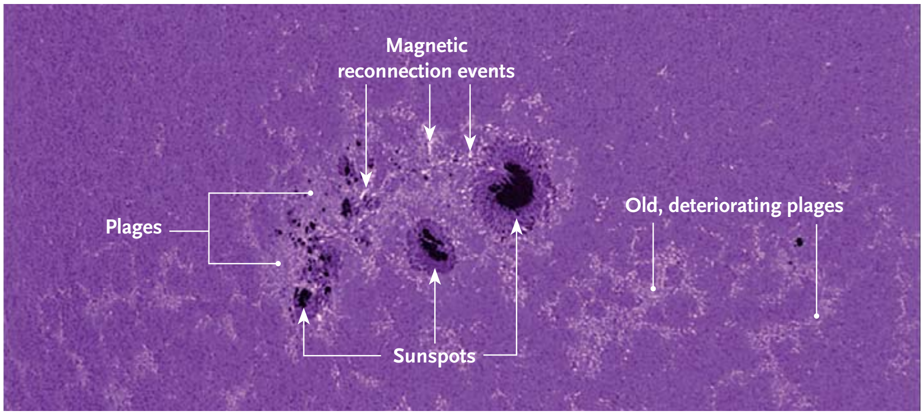
Explosive solar activity frequently appears as bright speckles within plages, caused by catastrophic reconnection of the Sun's intense magnetic fields. Sometimes called mini-flares, these speckles may extend for hundreds or thousands of kilometers. You can follow the evolution of this activity over several minutes, and sequential images may display these rapidly evolving changes. Occasionally, large regions of the plages and spots brighten quickly into powerful solar flares many times larger than Earth. These are exciting to watch as they brighten, expand, and then migrate and fade over a period of tens of minutes. Sometimes a ripple effect seems to trigger flares and reconnection events in adjacent active regions as well. In Ca-K light, it truly becomes possible to observe and follow the action within these active regions.

Evolution of solar activity is also visible on the solar limb in the form of plasma structures known as prominences that hover, quiver, and occasionally erupt into space. In 1891 George Ellery Hale used the calcium-H and

*Amateur astronomer **Howard Eskildsen** can often be found observing the Sun and Moon from his home in Ocala, Florida.*

Howard Eskildsen

Because some observers' eyes are not sensitive to near-ultraviolet wavelengths, it's easiest to share the view with others using a video camera, laptop computer, and a dark covering to shade the computer screen.



HOWARD ESKILDSEN (2)

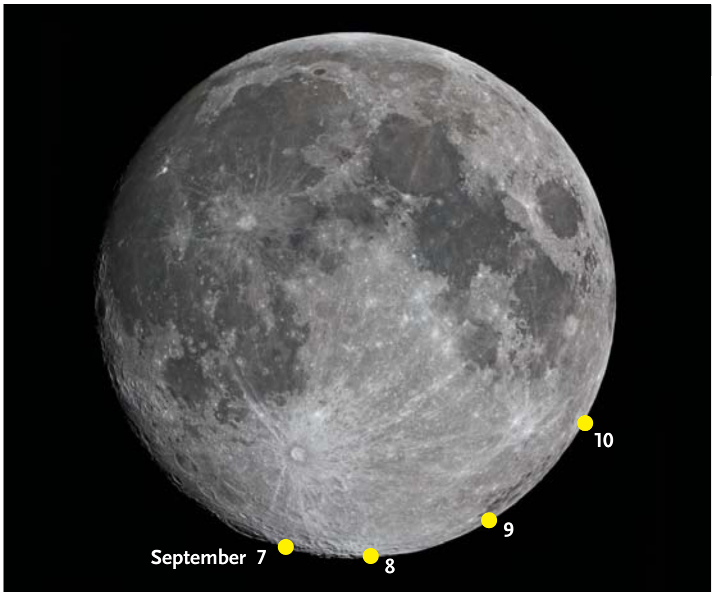
Sunspots appear very similar in Ca-K light as they do in white light. This similarity includes the dark umbral and lighter penumbral regions. But in Ca-K these features are always surrounded by bright plages connected to the intense magnetic fields associated with sunspots.

-K bands of a spectroheliograph to produce the first photographs of solar prominences taken when the Sun was not in eclipse. Although prominences are distinctly visible in Ca-K, they aren't as bright as when seen in Hα light, and to image them you'll need to increase the camera's exposure to the point of overexposing the solar disk.

Prominences appear in many different forms, such as jets, plumes, loops, and hedgerows. They may hover close to the solar limb or may extend tens of thousands of kilometers beyond the chromosphere. At first glance they appear stationary in space, but over several minutes prominences often reveal surprising changes in shape and size. You might see filaments of plasma streaming through the prominence or raining back down onto the Sun.

There are many options available for the solar observer to get in on this K-line action. These include dedicated solar scopes as well as specially designed filters that you can add to most refractors. Also, a wide range of high-quality video cameras are readily available at reasonable prices. I suggest a monochrome camera, because you'll be catching only a thin slice of the violet spectrum. Avoid color cameras for this work, because these models use built-in filters to generate a color image, and these filters often block the violet end of the spectrum. My solar setup consists of an Orion ED80 80-mm f/7.5 refractor with a Lunt Solar Systems B600 calcium K-line filter, and an Imaging Source DMK 41AF02.AS monochrome video camera connected to a laptop computer to display and record images.

For all that Ca-K has to offer, it's unfortunate that this purple Sun is so difficult to see visually. But with the help of a camera and monitor, anyone can see this exciting world of continuous solar action. ✦



S&T: DENNIS DI CICCO

The Moon • September 2014

Phases

FIRST QUARTER
September 2, 11:11 UT

FULL MOON
September 9, 1:38 UT

FIRST QUARTER
September 16, 2:05 UT

NEW MOON
September 24, 6:14 UT

For key dates, black dots on the map indicate what part of the Moon's limb is tipped the most toward Earth by libration under favorable illumination.

Distances

Perigee	September 8, 4^h UT
222,692 miles	diam. 33′ 20″
Apogee	September 20, 14^h UT
252,180 miles	diam. 29′ 26″

Librations

Kircher (crater)	September 7
Schomberger (crater)	September 8
Mare Australe	September 9
Phillips (crater)	September 10

The Theban Swan

Cygnus is alive with celestial treasures.

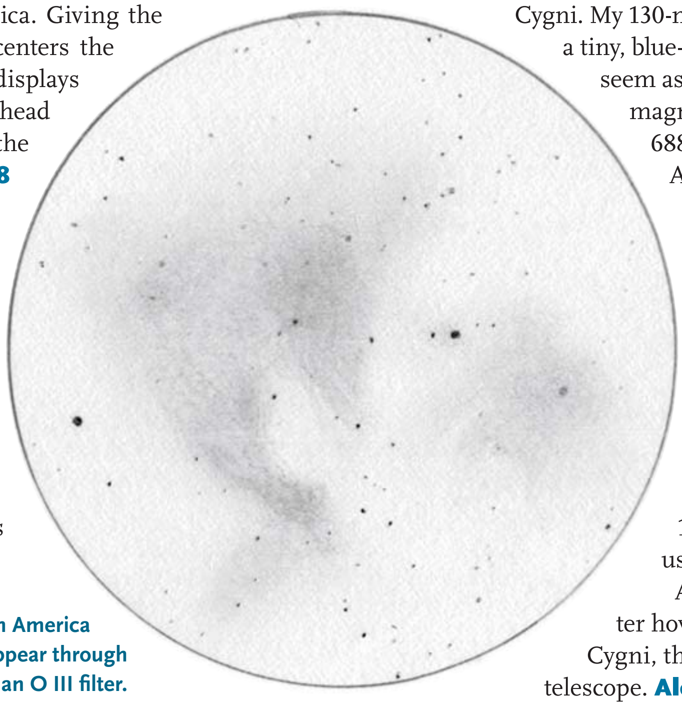
Lo, how th' obsequious Wind, and swelling Air
The Theban Swan do's upwards bear
Into the Walks of Clouds, where he do's play,
And with extended Wings opens his liquid way!
— Abraham Cowley, *The Praise of Pindar*, circa 1645

Cowley's praise of the ancient Greek poet Pindar imitates an ode by the Roman poet Horace, who lived four centuries after Pindar. In Cowley's poem the swan is Pindar of Thebes, yet we might imagine this passage applying to the constellation Cygnus as well. Gazing at Cygnus we see heaven's swan, his wings extended, as he glides along the celestial river of the Milky Way.

For someone with a small telescope that offers a very wide field of view, one of the finest sights in Cygnus is the **North America Nebula** (NGC 7000). In a 3.6° field at 17× with an O III filter, my 105-mm refractor shows off all of NGC 7000, as well as its neighbor the **Pelican Nebula**, as shown in the sketch below.

With a 2.7° field at 23×, my 130-mm refractor encompasses only one nebula at a time, but the view is: Wow! With this scope I prefer a narrowband filter, which reveals a wealth of subtle and not-so-subtle brightness variations within North America. Giving the scope a westward nudge centers the Pelican Nebula, which displays the distinctive shape of its head and the dark opening of the beak. The three **IC 5068** nebulae are visible south of the Pelican. The western one is the most obvious, the middle one a fair bit dimmer, and the eastern one quite faint.

An O III filter helps define the IC 5068 trio a little bit better, and the Pelican to a lesser extent. This filter greatly enhances the contrast between NGC 7000 and the surrounding sky, but it almost overwhelms the more delicate nuances within the nebula. It also diminishes the luster of the countless stars that beautify the scene. Yet you might find it necessary if your sky is more light-polluted than mine.



The author sketched the North America and Pelican nebulae as they appear through her 105-mm scope at 17× with an O III filter.

Best seen without a filter, a few star clusters adorn North America. **NGC 6997** is a rich dusting of faint to very faint stars where you'd expect to find West Virginia. In northern Canada, **NGC 6996** is a portion of the Milky Way enisled by dark nebulae. The combo is charmingly called the Dark Ring Nebula or Birds' Nest, with NGC 6996 as a clutch of eggs in the southern part of the nest. Boosting the power to 48×, I see **Collinder 428**, somewhere in the western states, as a 13′ group of 15 stars plus a detached group of six to the east. A gold 7th-magnitude star is parked on the cluster's eastern edge. With my 15-inch reflector at 221×, the little-known possible open cluster **Teutsch 22** appears in Arizona as a tight little gathering of a dozen faint to extremely faint stars about 2.6′ across. A 10.7-magnitude star pins its west-southwestern verge, and a 6.8-magnitude star sits 4.4′ north.

Next we'll visit the planetary nebula **NGC 6884**, which lies 37′ west-southwest of golden Omicron^1 (o^1) Cygni. My 130-mm refractor at 102× reveals a tiny, blue-green disk that doesn't seem as sharp as the stars. A 12th-magnitude star watches over NGC 6884 from 1.7′ west-northwest. At 164× the planetary doesn't look quite as colorful, but it displays a nice little disk with a fainter fringe.

Planetary-nebula distances are notoriously difficult to ascertain, but a study by Letizia Stanghellini and Misha Haywood (*Astrophysical Journal*, 2010) places NGC 6884 at 14,560 light-years away from us, plus or minus 20%.

Another obscure open cluster hovers 4.4° north of Omicron^2 Cygni, this one visible in a small telescope. **Alessi-Teutsch 11** is a 26′,

Stars, Clusters, and Nebulae in North Central Cygnus

Object	Type	Magnitude	Size/Sep.	RA	Dec.
North America Nebula	Emission nebula	3.8	2.0° × 1.7°	$20^h\ 58.0^m$	+44° 20′
NGC 6884	Planetary nebula	10.9	6.0″	$20^h\ 10.4^m$	+46° 28′
Alessi-Teutsch 11	Open cluster	—	26′	$20^h\ 16.4^m$	+52° 06′
NGC 6856	Open cluster	10.4	3.2′	$19^h\ 59.3^m$	+56° 08′
61 Cygni	Double star	5.2, 6.1	31.5″	$21^h\ 06.9^m$	+38° 45′
Berkeley 56	Open cluster	—	4.0′	$21^h\ 17.6^m$	+41° 50′

Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

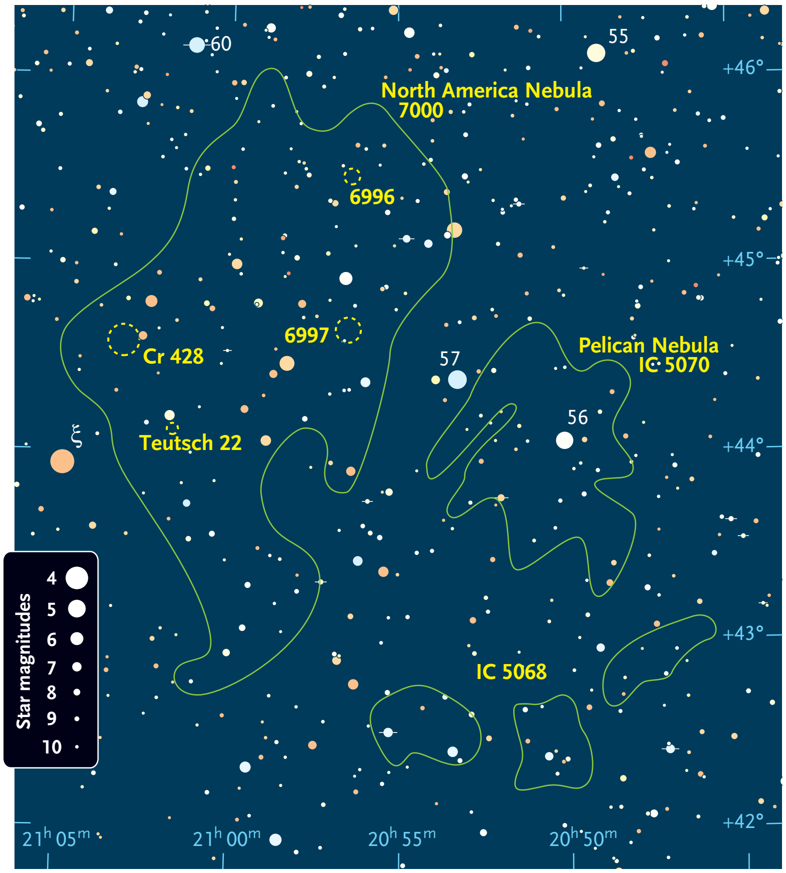
semi-detached splash of about 35 bright to faint stars as seen through my 105-mm refractor at 28×. The group covers about 26′ × 13′, elongated northeast-southwest. Its two brightest stars are magnitude 7, the northern one shining yellow-orange. Some lovely multiple stars inhabit the field. ES 2692 is a nicely matched, east-west pair of 9.6-magnitude stars that lies off the cluster's eastern side. North of the cluster, OΣ 404 is a wide double made up of a bright gold star with a considerably fainter companion to its east-southeast. At low power ES 660 looks like two unequally bright stars sitting east of and making the pointy end of an isosceles triangle with the cluster's two brightest stars. However, boosting the magnification to 87× shows that the apparently brighter member of the pair is actually two closely spaced stars, and ES 660 becomes a cute little arc of 10th-magnitude suns.

Alessi-Teutsch 11 is thought to be 1,800 light-years distant and 140 million years old.

Sliding 1.6° south-southeast from 23 Cygni brings us to the open cluster **NGC 6856**. It looks very small through my 130-mm refractor at 37×, revealing only two faint stars and several very faint ones that show better with averted vision. A golden 8th-magnitude star lies 12.5′ to its west-northwest. At 164×, I count nine stars in a blocky, 2′ × 1½′ group and one outlying star to the east. The central knot is a tight little collection of 13 stars through my 10-inch reflector at 187×.

NGC 6856 is missing from many lists of deep-sky objects because it was deemed nonexistent in the *Revised New General Catalogue of Nonstellar Astronomical Objects* (Jack W. Sulentic and William G. Tifft, 1973). Nonetheless, it's fairly obvious in backyard scopes. NGC 6856 is now considered to be a true cluster. It is very old — 1.8 billion years — and 5,600 light-years away from us.

On the opposite side of the North America Nebula, let's call on the attractive double star **61 Cygni**, also known as Piazzi's Flying Star or Bessel's Star. It's one of the closest star systems to the Sun, only 11.4 light-years away. The pair's motion through space and nearness to us give it an extraordinarily rapid apparent motion across the backdrop of distant stars. The motion is particularly easy to detect now, because the brighter component is flying past a 10.7-magnitude background star, as described on page 50 of the August issue.



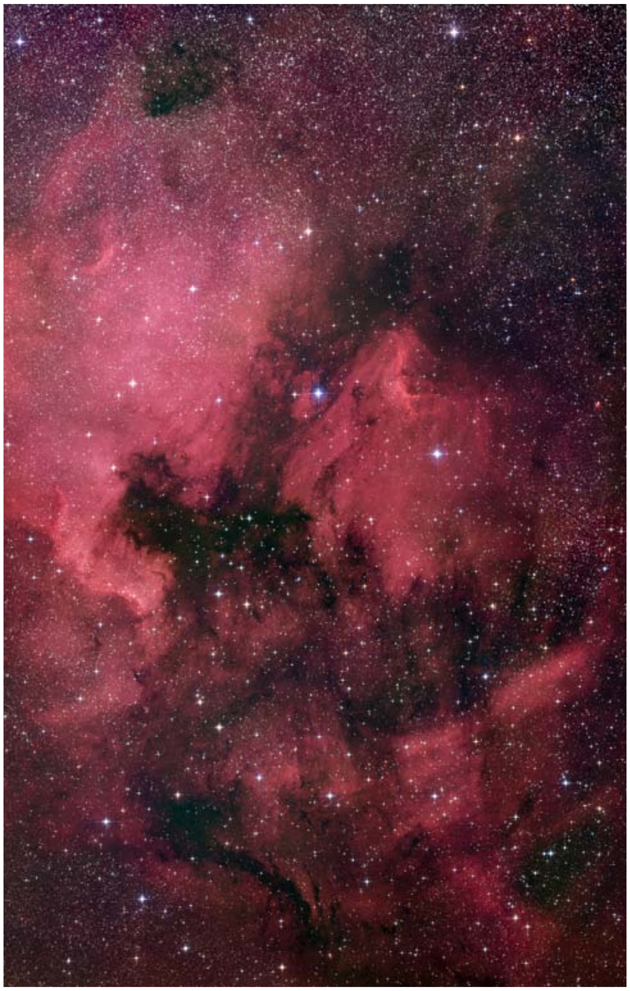
In 1804 Giuseppe Piazzi deduced the large proper motion of 61 Cygni from previous observations made by himself and others, and he cataloged the results two years later. In 1838 Friedrich Wilhelm Bessel calculated the distance to 61 Cygni based on precise measurements of the star's parallax — the shift in its apparent position due to Earth's changing perspective as it orbits the Sun. That was the first accurate measurement of the distance to any object outside our solar system.

Through my 130-mm scope at 23×, 61 Cygni's primary star appears deep gold, and its modestly fainter companion to the south-southeast looks a bit more orange to me. In reality, the two stars have nearly the same spectral type, the brighter one *K*5 and the dimmer one *K*7, which weigh in at three-fourths and one-half the mass of our Sun, respectively. What colors do you see?

Climbing 2.4° north from Sigma (σ) Cygni we come to the exceptionally ancient open cluster **Berkeley 56**. A 2011 *Astronomical Journal* paper by Kenneth A. Janes and Sadia Hoq puts it at 6 billion years old and 36,000 light-years away from us.

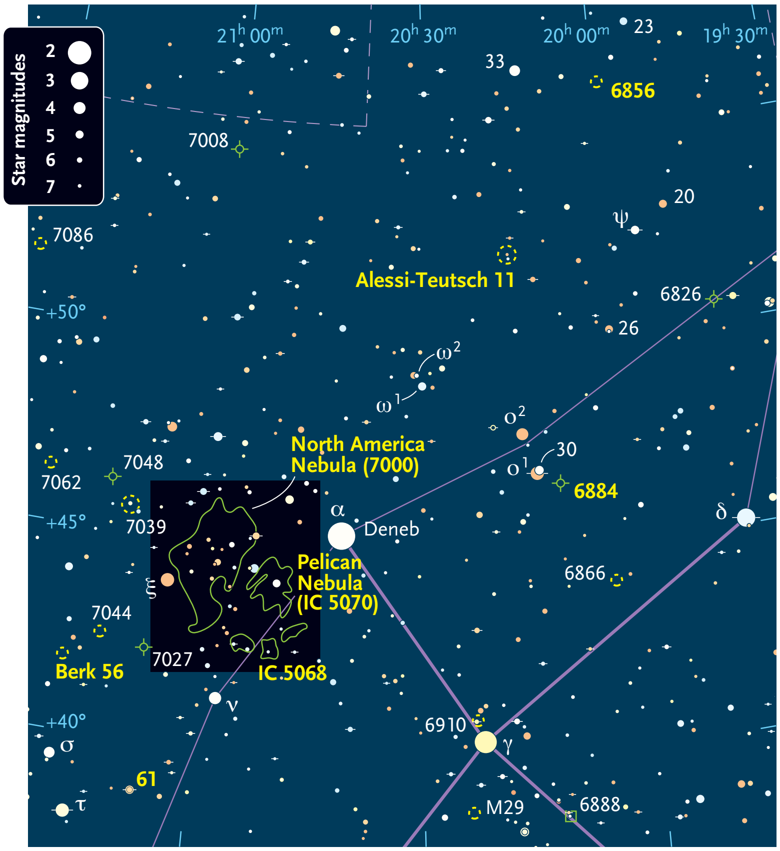
Through my 10-inch reflector at 43×, Berkeley 56 is a faint, grainy powder. Two stars closely guard its northwest quadrant, magnitudes 10.5 and 12.3. Perched north of the cluster, a distinctive pattern of five 9th- to 12th-magnitude stars forms a slender V that has slightly curved sides and points northwest. At 115× four stars arc across the haze, two in the south-southwestern edge, one at the center, and one in the northern edge. At 213× several extremely faint stars dot the haze, but these are probably in the foreground. The brightest possible cluster member listed by Janes and Hoq is magnitude 14.3, and the rest are magnitude 15.6 and fainter.

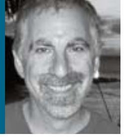
Berkeley 56 is exceedingly rich in stars, otherwise it wouldn't have been able to hold itself together for such a long time. Janes and Hoq catalog 997 possible members, most well beyond the reach of amateur telescopes. How many stars can those of you with very large scopes pry out of the haze? ✦



ROBERT GENDLER

This photomosaic makes it clear why the North America Nebula got its name. The Pelican Nebula, to its right, is harder to make out because the deep exposure tends to fill in the dark nebula that divides the beak from the body. IC 5068 is the tripartite nebula below the Pelican





Seeking Interacting Galaxies

The Vorontsov-Velyaminov catalog is a mother lode of close galaxy pairs.

THE *PALOMAR OBSERVATORY Sky Survey*, conducted from 1949 to 1956 using the 48-inch Oschin Schmidt Telescope, recorded stars as faint as 21st magnitude, along with countless deep-sky objects. The 936 pairs of blue- and red-sensitive plates provided one of the most important resources for astronomical research for the next several decades.

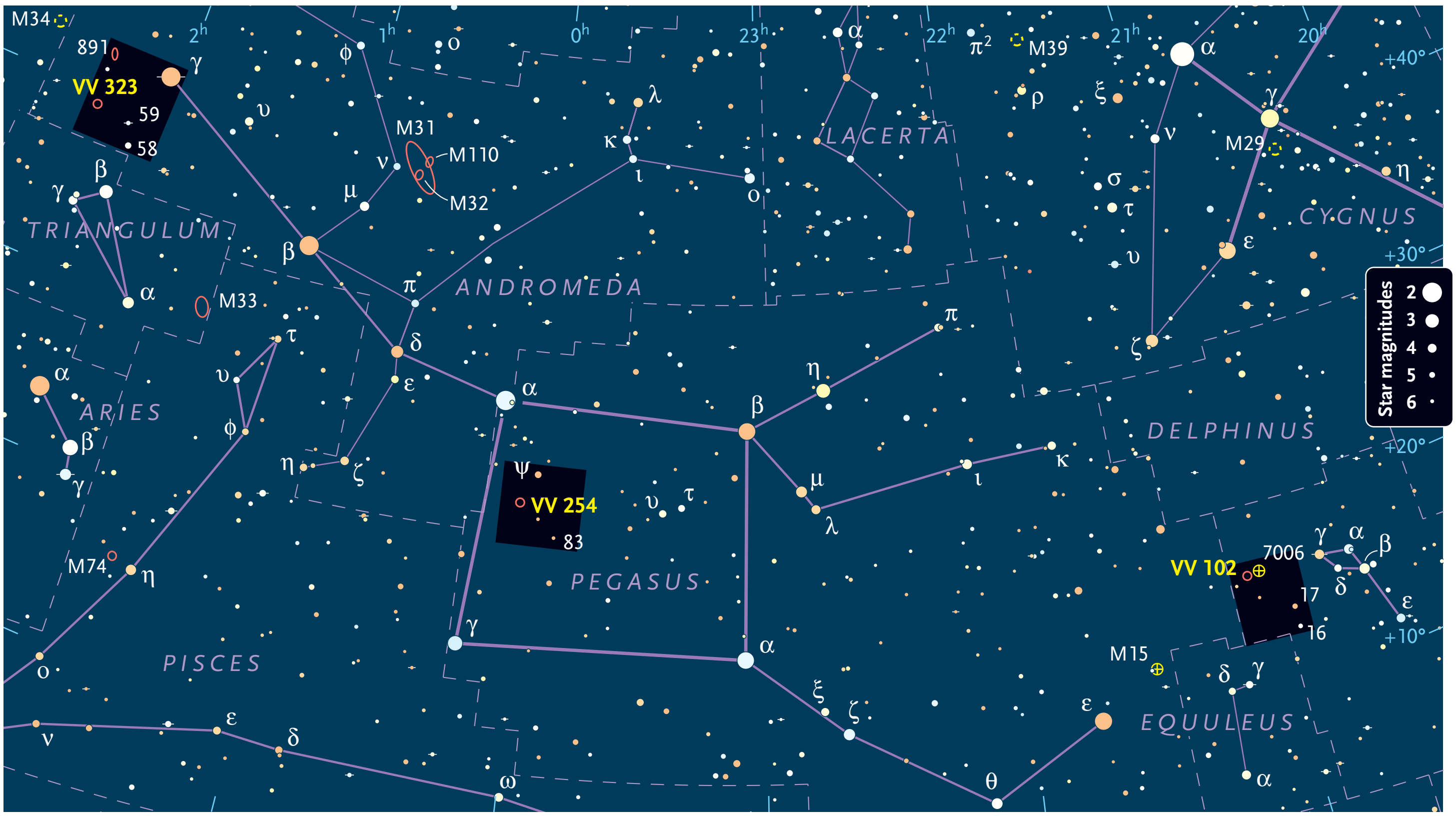
One of the first studies based on the new sky survey was the 1959 *Atlas and Catalogue of Interacting Galaxies* by Russian astronomer Boris Vorontsov-Velyaminov. It lists 355 systems with designations VV 1 through VV 355. Although some were previously known, Vorontsov-Velyaminov discovered most of them by visual inspection of the *Palomar Observatory Sky Survey* plates.

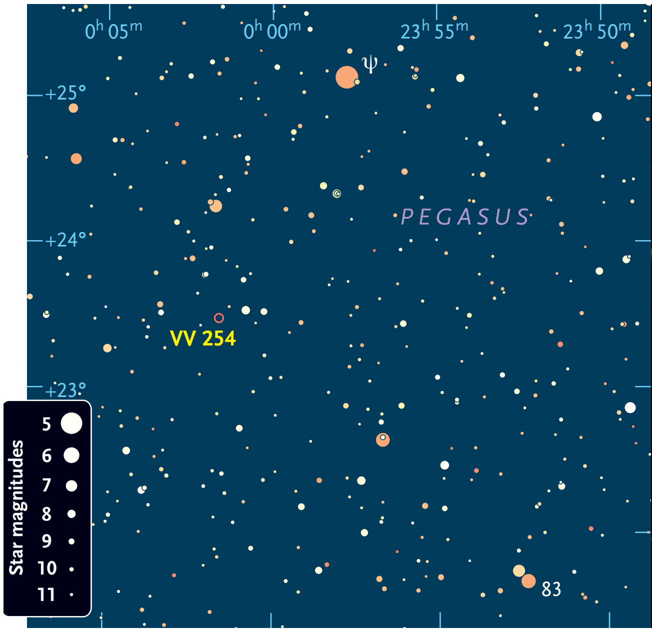
The first VV atlas divides interacting galaxies into 20 classes such as "merging or in contact," "nests of galaxies," and "chains with bridges." It also notes various interactions, such as tidal tails, distortions, and rings. The atlas showcases a number of bizarre, gravitationally deformed galaxies, and it caught the attention of the

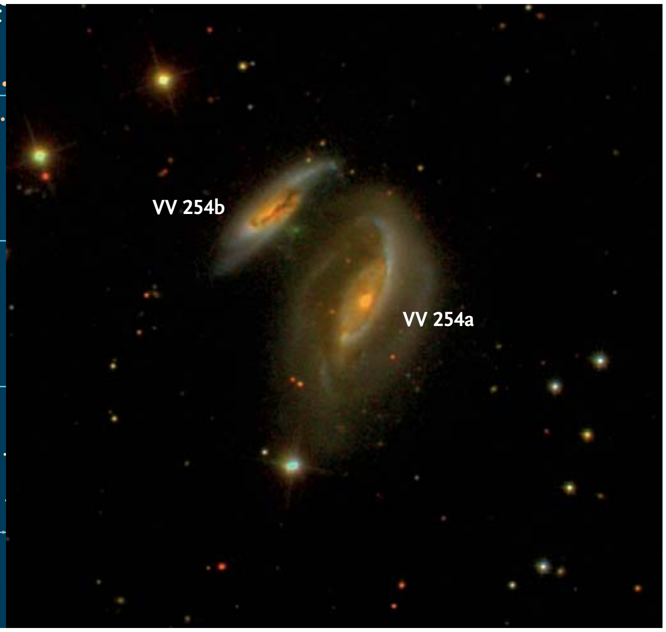
Selected Vorontsov-Velyaminov Galaxy Pairs

Name	UGC	Mag(s)	Const.	RA	Dec.
VV 254	12914, 12915	12.5, 13.0	Peg	0^h 01.6^m	+23° 29′
VV 323 (Arp 273)	1810, 1813	12.6, 14.2	And	2^h 21.5^m	+39° 23′
VV 102	11672	~14.5	Del	21^h 04.5^m	+16° 05′

Visual magnitudes have been estimated by correcting the blue magnitudes in the *Third Reference Catalog of Bright Galaxies* for galaxy type. Only a combined magnitude is available for VV 102; the components are too tightly bound to measure separately. Right ascension and declination are for equinox 2000.0.







SLOAN DIGITAL SKY SURVEY

gifted, controversial astronomer Halton Arp. More than half of the 338 entries in Arp's 1966 *Atlas of Peculiar Galaxies* appeared earlier in the VV atlas.

In 1977 Vorontsov-Velyaminov published part II of his atlas. This supplement expanded the list of interacting galaxies to 852 and added new categories such as "galaxies of the M51 type," "chains in the making," and "blue nests." Finally, a 2001 update merged the first two catalogs and added 1,162 more interacting galaxies, bringing the designations up to VV 2014.

Although a 6- to 10-inch scope will reveal a number of the brighter VV systems, you'll probably need at least a 16-inch to view structural features of the interactions.

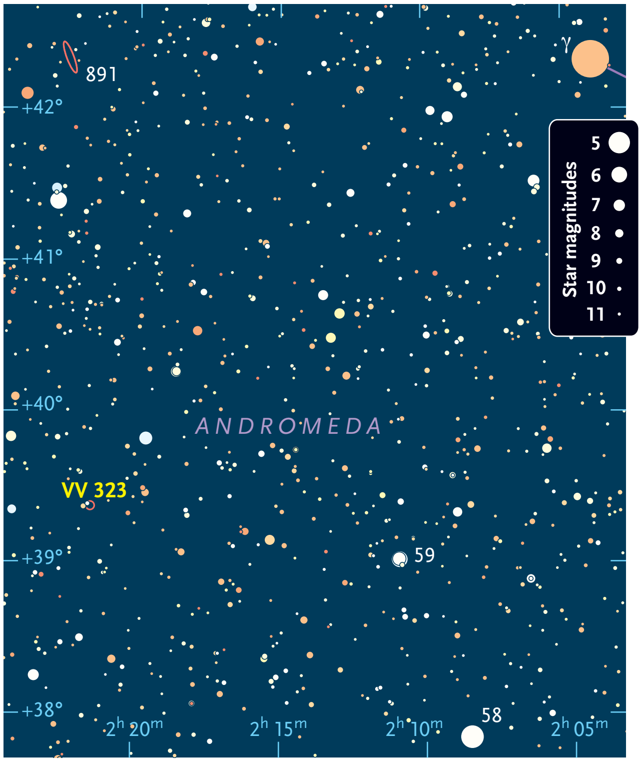
Heavenly Taffy

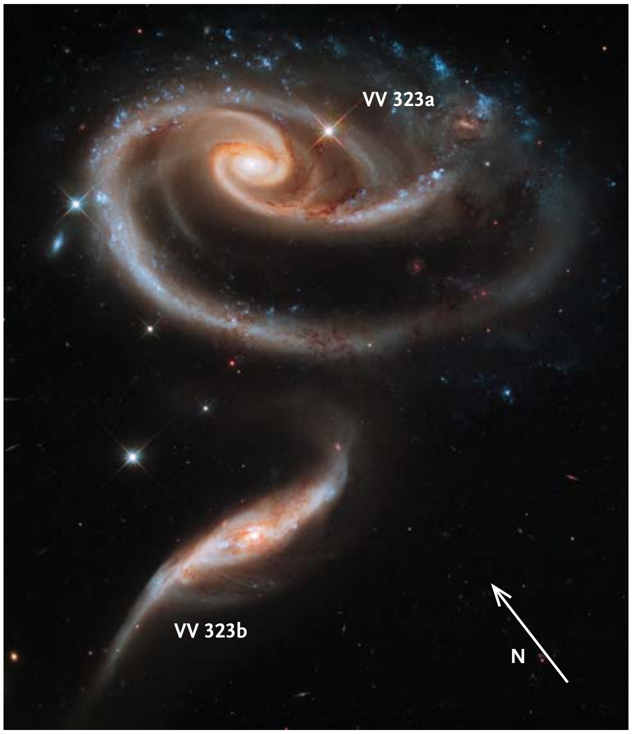
VV 254 is located along the eastern side of the Great Square of Pegasus, 5.8° south-southwest of 2.1-magnitude Alpheratz (Alpha Andromedae). It consists of two gas-rich spirals (UGC 12914 and 12915) receding from each other in the aftermath of a head-on collision that took place roughly 20 million years ago. In a 1993 study published in the *Astronomical Journal*, radio astronomer Jim Condon and colleagues coined the nickname Taffy Galaxies, because a radio-emission contour map of the gas bridge connecting the pair resembles strands of pulled taffy.

Through my 24-inch reflector at 375×, the Taffy Galaxies appear to be reaching out to each other. VV 254a, a 12.5-magnitude spiral stretching 1.6′ × 0.8′, is concentrated to a small, rounder core. A spiral arm emerges from the north-northwest end of the core and arcs toward VV 254b, just 1′ northeast. The 13th-magnitude companion spans 1.0′ x 0.4′ and also harbors a bright, compact core. From the northwest end of VV 254b, a short extension bends west toward VV 254a.

Hubble's Rose of Galaxies

Photogenic **VV 323** lies in easternmost Andromeda, 3.0° due south of the classic edge-on spiral galaxy NGC 891. Like the Taffy Galaxies, VV 323 is thought to be a post-collision result, with VV 323b (UGC 1813) piercing off-center through VV 323a (UGC 1810). The celestial mayhem disrupted VV 323a, resulting in highly warped spiral arms, a partial outer ring, and numerous blue knots of young, massive stars. Halton Arp included VV 323 in his category





NASA / ESA / HUBBLE HERITAGE TEAM

of "double galaxies with connected arms," so it also carries the designation Arp 273.

Both of VV 323's components show up faintly in my 18-inch reflector, but details are fleeting. Through Jimi Lowrey's 48-inch leviathan at 488×, 12.6-magnitude VV 323a has a chaotic, lopsided appearance. A prominent 15″ core condenses to a nearly stellar nucleus, and a 13.5-magnitude star is pinned to its west side. A narrow spiral arm emanates from the north side of the core and rotates counterclockwise east to a 14.5-magnitude star, then shoots south toward 14th-magnitude VV 323b, a 40″ × 10″ splinter trending east-west. Σ251, an attractive 2″-wide pair of 9th- and 10th-magnitude stars, lies 3′ east.

A Merging Duo

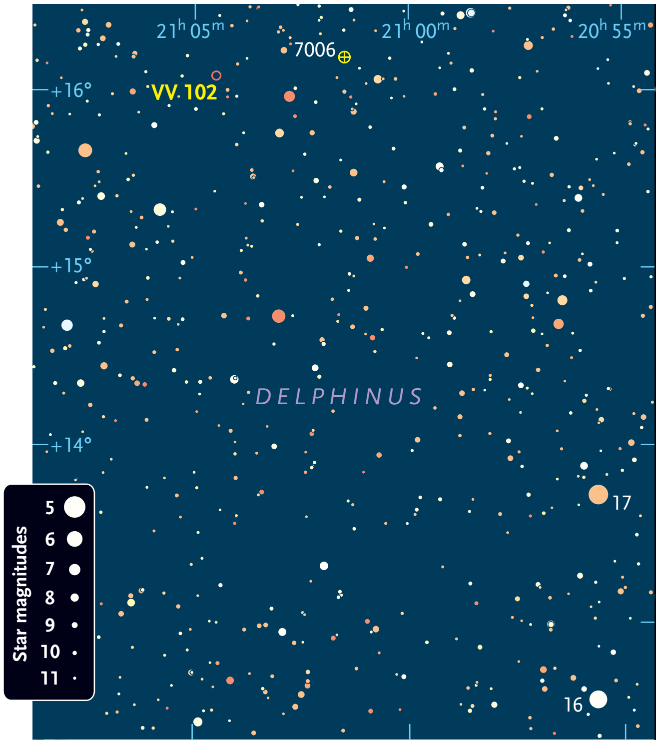
Vorontsov-Velyaminov placed **VV 102** (UGC 11672) in his interaction category of "coalescent pairs." It resides a mere 45′ east-southeast of the small globular cluster NGC 7006 in Delphinus and a similar distance west-southwest of a 12′ asterism that *Deep-Sky Wonders* columnist Sue French dubbed the "Toadstool."

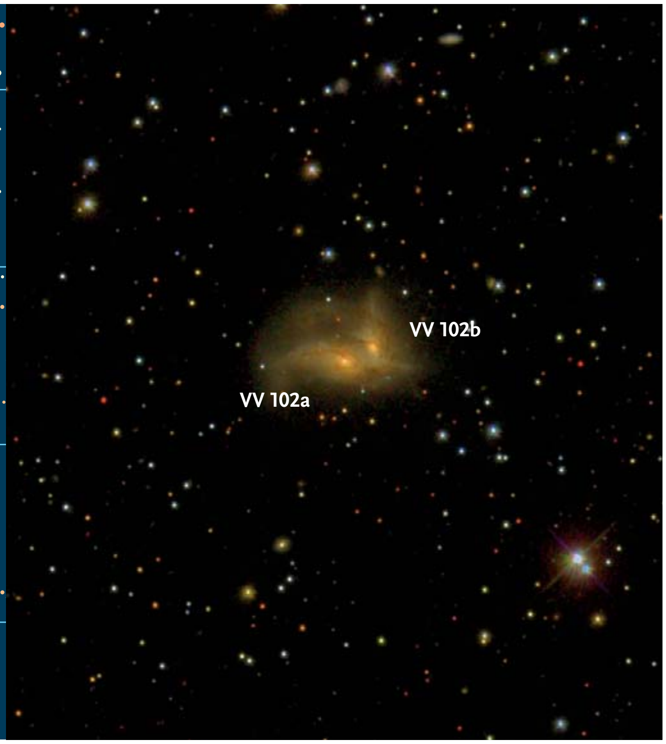
The SDSS image below shows a fused double system with two nuclei separated by just 16″. At a redshift-based distance of roughly 420 million light-years, the twin nuclei might be as little as 35,000 light-years apart, depending how they're oriented to our line of sight.

Despite the tight separation, I could resolve the pair at 375× in my 24-inch. VV 102a, the slightly brighter eastern component, is a fairly faint 30″ irregular glow with a patchy surface brightness. VV 102b is a small 18″ knot jammed against the west side of VV 102a's halo.

You can find a scanned version of the original VV atlas at **ned.ipac.caltech.edu/level5/catalogs.html**. For a challenging observing project, Alvin Huey provides a downloadable guide at **www.faintfuzzies.com**. ✦

*Contributing editor **Steve Gottlieb** welcomes questions and comments at steve_gottlieb@comcast.net.*





SLOAN DIGITAL SKY SURVEY

20 fun Naked-Eye Double Stars

JERRY LODRIGUSS

From easy to challenging, here are some star pairs every skywatcher should know.

Because I take astrophotos all the time, some people think I never do any observing. But once I get an exposure run going, I start looking around. If I'm out with friends I'll observe through their scopes. More often I'm by myself, and then I use either binoculars or just my eyes.

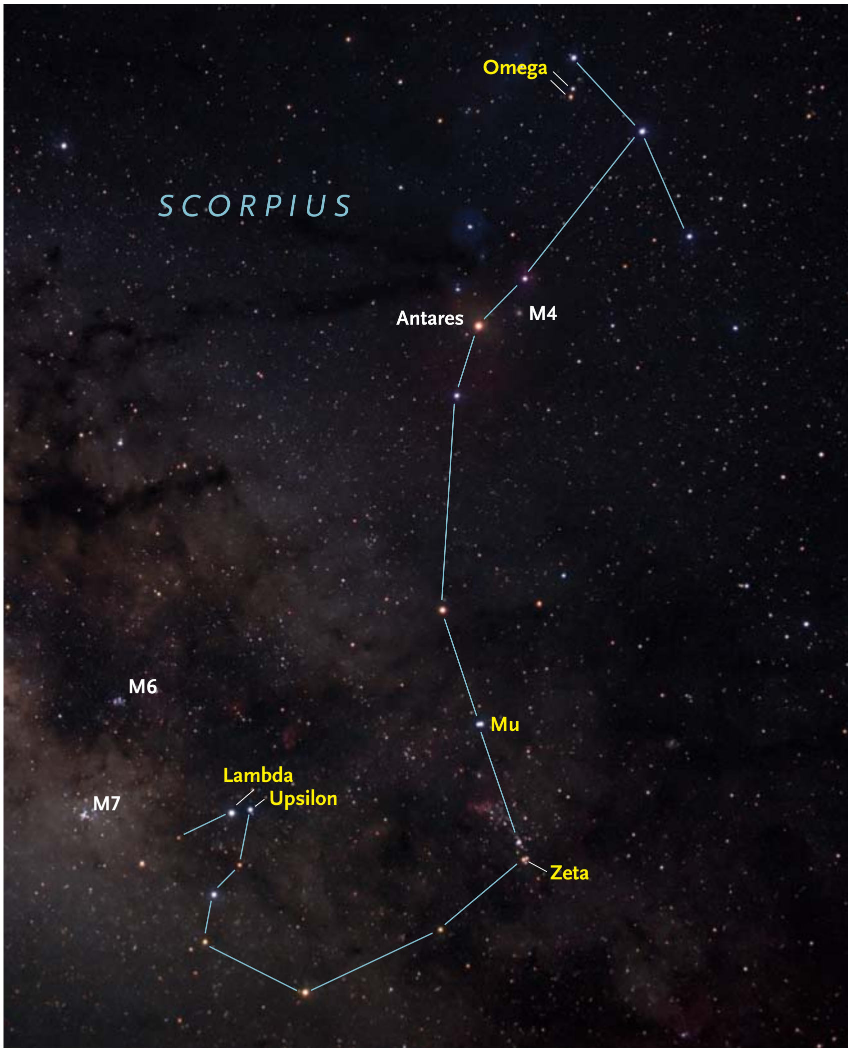
I've done *a lot* of naked-eye observing. It never pales. Sitting under a clear, dark sky as the rest of the universe passes overhead in majestic splendor is a profound and astonishing experience. And there's almost no end of new things to discover.

One pastime I've come to enjoy is naked-eye double-star observing. My favorite showcase examples are Theta Tauri, Alpha Capricorni, Epsilon Lyrae, the Cat's Eyes pair in Scorpius, and Mu Scorpii. But you can see many more.

Of course, this pursuit has its limits. The human eye could theoretically resolve about ½ arcminute if it were made with machine perfection, but in the real world, folks with excellent eyesight can resolve about 2 arcminutes. With average eyesight, you can resolve 3′. A lot also depends on the brightness of the two stars and especially the brightness difference between them.

A note on terminology: Not all *double* stars are *binary* stars. A binary is a true physical pair whose members orbit each other. "Double stars" include both binaries and *optical doubles,* pairs that merely look close together on the sky but whose stars are at different distances and physically unrelated. If a double is wide enough to be resolved with the naked eye, it's usually an optical pair.

Here's my list of favorites. It starts with those you can see on August and September evenings, then works the rest of the way around the night and the year. Given for each star are its separation in arcminutes and the direction of the fainter star from the brighter one, then the



ALL PHOTOS BY JERRY LODRIGUSS

magnitude, spectral type, and distance in light-years of each. The distances are inexact, more so the farther out you go, so when the values look similar they *may* in fact be essentially the same and the two stars may be a true binary. Mizar and Alcor are a case in point.

Mizar & Alcor, separation: 12′ (ENE)
Mizar: mag. 2.2, *A*2V, 78 l-y
Alcor: mag. 4.0, *A*5V, 82 l-y
Easy. R.A. 13^h 24^m, Dec. +54.9°
This most famous of naked-eye doubles, at the bend of the Big Dipper's handle, was long considered a test of keen eyesight. But in the modern era of good eyeglasses it's no great challenge for most people, with its separation of ⅕°. A small telescope resolves Mizar itself into a much closer double star, separation 14 arcseconds.

Alpha Librae (Zubenelgenubi), separation 3.8′ (NW)
Alpha^2 Lib: mag. 2.8, *A*3III/V, 77 l-y
Alpha^1 Lib: mag. 5.2, *F*3V, 75 l-y
Very difficult. R.A. 14^h 52^m, Dec. –16.1°
Famous as a wide and easy pair in binoculars, Alpha Librae's toughness to resolve naked-eye may be surprising — until you imagine Mizar and Alcor three times closer together, and with a greater magnitude difference!

When Greek-lettered stars have superscript numbers, the numbers are not in order of brightness but right ascension from west to east. This was the order they crossed the north-south hairline in a meridian transit telescope, the first really accurate tool for measuring star positions.

Omega Scorpii, separation 15′ (SSE)
Omega^1: mag. 3.9, *B*1V, 470 l-y
Omega^2: mag. 4.3, *G*7III, 290 l-y
Easy. R.A. 16^h 07^m, Dec. –20.7°
This lovely naked-eye optical double adds to the overall fascination of the district around Antares and the head of Scorpius, as shown at left. Look for a color difference.

Mu Scorpii (Little Cat's Eyes), separation 5.8′ (ENE)
Mu^1 : mag. 3.0, *B*1.5Vp, 500 l-y
Mu^2: mag. 3.6, *B*2IV, 470 l-y
Showcase close naked-eye double! R.A. 16^h 53^m, Dec. –38.1°
Beautiful but close — and low. If you're at 40° north latitude, Mu never rises more than 12° high.

Zeta Scorpii, separation 6.5′ (W)
Zeta^2: mag. 3.6, *K*4III, 130 l-y
Zeta^1: mag. 4.7, *B*1Ia-*O*ek, 2,500 l-y
Moderately difficult. R.A. 16^h 55^m, Dec. –42.4°
Zeta Sco is even lower for northern observers; it's 4° south of Mu. For the truly keen-eyed, a third, 5.8-magnitude star lies 7 arcminutes to the pair's south. Just north of Zeta is the bright, sprawling open cluster NGC 6231, adding to the False Comet asterism.

Observing Tips

- Use your arm to block out low-altitude light pollution from view, or make "air binoculars" with your curled hands.
- Get your vision tested, and make sure your glasses' prescription is up to date. Consider acquiring a second pair optimized for astronomy, perhaps by applying –½ or –¾ diopter to your regular prescription for each eye. For many people, this offsets their night myopia, which is generally strongest in youth and decreases with age. (See "Spectacles for Spectacular Skies," *S&T*: Sept. 2005, p. 30.)
- Get low-reflection coated eyeglass lenses; they transmit more light and scatter less.
- Observe often to gain experience. You'll be surprised at the difference this makes.

Lambda & Upsilon Scorpii (Cat's Eyes), separation 36′ (WSW)
Lambda (Shaula): mag. 1.6, *B*2IV, 570 l-y
Upsilon (Lesath): mag. 2.7, *B*2IV, 580 l-y
Easy. R.A. 17^h 34.6^m, Dec. –37.1°
The Cat's Eyes in the stinger of Scorpius are unequal and are usually seen tilted; maybe the cat is wobbling. Both are hot blue stars in the enormous Scorpius-Centaurus Association of young stars. It's hard to believe, but their separation of 36′ is slightly wider than the full Moon. A line from Lambda through Upsilon points to Mu.

Epsilon Lyrae (Double Double), separation 3.5′ (N)
Epsilon^2: mag. 4.6, *A*6Vn + *A*7Vn, 160 l-y
Epsilon^1: mag. 4.7, *A*3V + *F*0V, 160 l-y
Showcase difficult pair. R.A. 18^h 45^m, Dec. +39.7°
This famous pair is a real challenge because of the stars' closeness and faintness, but at least they're nearly equally bright. Good luck! A telescope at 100× or more resolves each in turn into a close binary.

Delta Lyrae, separation 10′ (WNW)
Delta^2: mag. 4.2, *M*4II,750 l-y
Delta^1: mag. 5.6, *B*2.5V, 1,000 l-y
Moderately difficult. R.A. 18^h 54^m, Dec. +37.0°
Another famous binocular pair, easier to resolve naked-eye than Epsilon due to its wide separation.

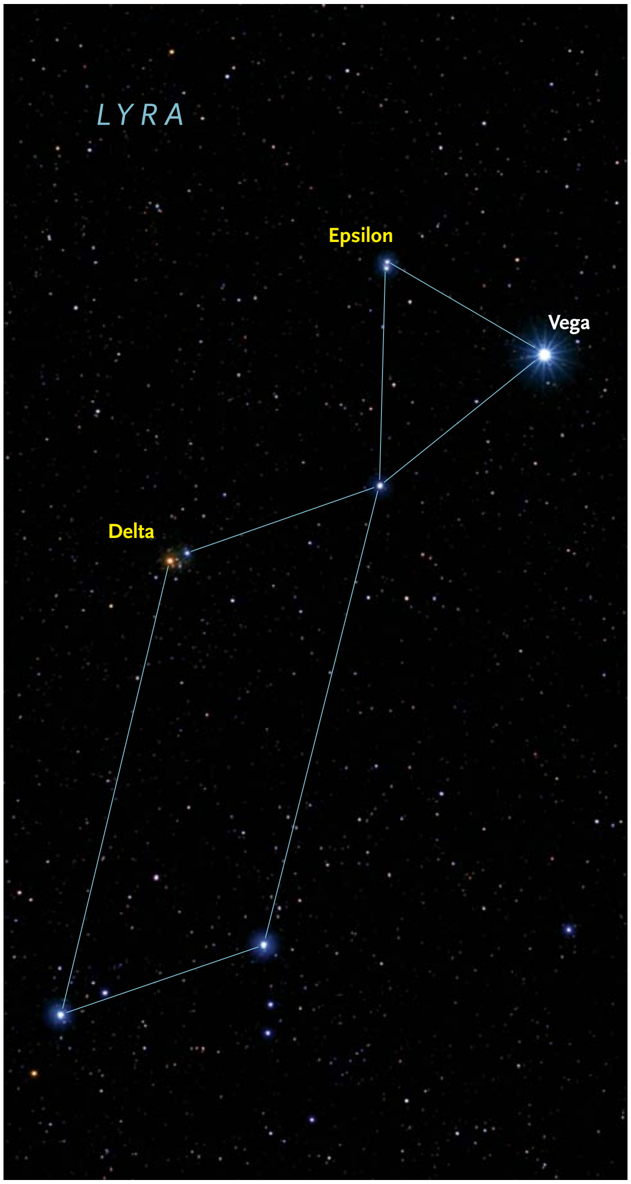
Nu Sagittarii, separation 14′ (ENE)
Nu^1: mag. 4.9 , *K*1II, 1,100 l-y
Nu^2 mag. 5.0, *K*1Ib/II, 275 l-y
Easy. R.A. 18h 55m, Dec. –22.7°
Bet you didn't know this one! Nu Sagittarii is south of the tip of the Sagittarius Teaspoon, about a third of the way from there to Nunki, the brightest star in the handle of the Teapot. The Nu stars are faint but fairly wide. Binoculars reveal lots of deep-sky wonders around here.

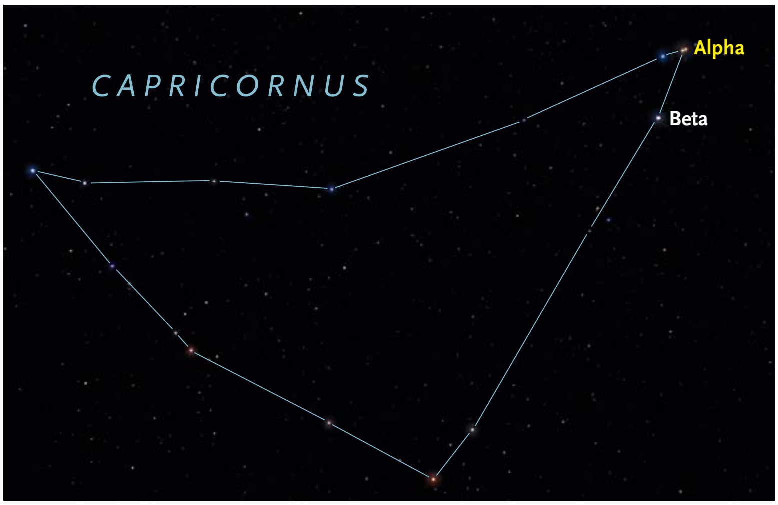
Omicron[1] & Omicron[2] Cygni, separation 61′ (NNE)
Omicron[1]: mag. 3.8, *K*2II, 900 l-y
Omicron[2]: mag. 4.0, *K*3Ib, 1,050 l-y
Easy. R.A. 20^h 14^m, Dec. +46.8°
Omicron[1] & 30 Cygni, separation 5.6′ (NW)
Omicron[1]: mag. 3.8, *K*2II, 900 l-y
30 Cyg : mag. 4.8, *A*5IIIn, 600 l-y
Moderately difficult. R.A. 20^h 14^m,Dec. +46.8°

The two Omicron stars in Cygnus, 5° from Deneb, are so far apart that they're a double only under the loosest definition. The challenge here is Omicron[1] Cygni and its much closer neighbor, 30 Cygni. Binoculars and telescopes split Omicron[1] into an orange-red and bluish pair, which make a lovely triple with white 30 Cygni.

Alpha Capricorni (Algedi), separation 6.3′ (WNW)
Alpha[2]: mag. 3.6, *G*8.5III-IV, 105 l-y
Alpha[1]: mag. 4.3, *G*3Ib, 570 l-y
Showcase naked-eye double! R.A. 20^h 19^m, Dec. –12.5°
The western tip of Capricornus is one of the loveliest naked-eye doubles in the sky. Although they're just an optical pair, both stars are yellow giants, and both have extremely faint telescopic companions.

Sterope, separation 2.5′ (SE). In the Pleiades.
21 Tauri: mag. 5.8, *B*8V, 370 l-y
22 Tauri: mag. 6.4, *A*0Vn, 380 l-y
Extremely difficult. R.A. 3^h 47^m, Dec. +24.6°
Altas & Pleione, separation 5.0′ (N). In the Pleiades.
27 Tauri (Atlas): mag. 3.6, *B*8III, 380 l-y
28 Tauri (Pleione): mag. 5.0, *B*8Vne, 380 l-y
Moderately difficult. R.A. 3^h 50^m, Dec. +24.1°
The Pleiades contain two naked-eye challenge pairs. The famous Atlas and Pleione are the legendary parents of the Seven Sisters. I rank them as only moderately difficult, a beautiful pairing amidst the other jewels of the Pleiades if you can manage it. The Sterope (or Asterope) pair, on the other hand, is very tight and very faint as well.





Theta Tauri, separation 5.6′ (NNW). In the Hyades.
Theta[2]: mag. 3.4, *A*7III, 150 l-y
Theta[1]: mag. 3.8, *K*0IIIb, 155 l-y
Showcase naked-eye double! R.A. 4^h 29^m, Dec. +16.0°
Delta Tauri, separation 18′ (ESE). In the Hyades.
Delta[1]: mag. 3.8, *G*9.5III, 155 l-y,
Delta[2]: mag, 4.8, *A*2Vs, 160 l-y
Fairly easy. R.A. 4^h 24^m, Dec. +17.6°
The Hyades contain two much easier targets. Theta Tauri, near Aldebaran, is right up there with Alpha Capricorni as one of the finest near-equal naked-eye pairs in the sky. Binoculars show a color difference: orange and bluish.

In the opposite arm of the Hyades' V pattern, the Delta[1]-Delta[2] pair is fainter but much wider. Delta[3] Tauri, twice as far to their northeast, outshines faint Delta[2] by a half magnitude and forms an elongated triangle with the closer Deltas.

42 & 45 Orionis, sep. 4.2′ (ESE). In Orion's Sword.
42 Ori: mag. 4.6, *B*1V, 900 l-y
45 Ori: mag. 5.2, *F*0III, 360 l-y
Very difficult. R.A. $5^h\,36^m$, Dec. −4.8°

Theta Orionis, sep. 2.2′ (NW). In Orion's Sword.
Theta^2: mag. 5.0, *B*1, 1,400 l-y
Theta^1: mag. 5.1, *B*0.5V, 1,400 l-y
Extremely difficult. R.A. $5^h\,36^m$, Dec. −5.4°

Iota Orionis, sep. 8′ (SW). In Orion's Sword.
Iota: mag. 2.8, *O*9III, 2,300 l-y
Σ747: mag. 4.7, *B*0.5V, 1,600 l-y
Moderately difficult. R.A. $5^h\,36^m$, Dec. −5.9°

The familiar Sword of Orion is a complex and fascinating area in binoculars and telescopes. But did you know that each of its three brightest stars is a challenging naked-eye pair?

The northern pair consists of 42 and 45 Orionis. They're embedded in a very faint nebula for telescopes under dark skies.

The toughest is Theta^1 and Theta^2 in the brightest part of the Great Orion Nebula; they're the closest pair in this entire list, very faint, and they contend with the nebulosity and other stars in the immediate area. I've never been able to split them, but it might just be possible for someone with exceptional eyesight and observing skills.

At the south end of Orion's Sword is the least difficult pair: bright Iota Orionis and its neighbor Struve 747. The latter is a lovely binocular double, magnitudes 4.8 and 5.7, separation 0.6′.

Zeta Corvi, separation 6′ (WNW)
Zeta: mag. 5.2, *B*8V, 420 l-y
HD 107295: mag. 5.9, *K*0III, 400 l-y
Moderately difficult. R.A. $12^h\,21^m$, Dec. −22.3°

Jumping forward into the spring sky, Zeta Corvi and its companion lie within the four-star "sail" pattern of Corvus. This constellation is never very high, and the Zeta double is a challenge for its faintness.

I often imagine myself sharing the sky with our pre-technological ancestors, who only had their unaided eyes with which to explore the stars and find these pairings. I imagine that they must have found this pursuit fascinating too. ✦

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*Jerry Lodriguss is an author, professional photographer, and educator who writes about and teaches astrophotography. For more of his images of the double stars in this article, see **www.astropix.com/doubles**.*

CONQUERING Gradients

Get the most out of this powerful technique in PixInsight.

Rogelio Bernal Andreo

Gradients. *It's the one thing every deep-sky astrophotographer has to deal with sooner or later. They appear in images as an uneven background, often introducing unwanted color biases and overpowering the signal of your subject galaxy, nebula, or star cluster. In an ideal world, astrophotographers wouldn't have to address gradients, and we wouldn't have to worry about things such as noise, either. But unlike noise, we can remove gradients from our images without compromising the underlying data.*

ALL PHOTOS ARE COURTESY OF THE AUTHOR

Understanding the Problem

Gradients are often due to unwanted light sources such as light pollution, but there are many natural light sources that will introduce gradients to your deep-sky images, including the zodiacal light, aurorae, and even natural airglow. Each of these light sources add signal to your images — an unwanted signal.

Because gradients are unwanted signal in our photos, the most accurate way of removing them is to mathematically subtract them from the image. Ideally, this subtraction should be the first thing you do to your calibrated images before any stretching or sharpening. At this stage your image is linear (unstretched), which is the best time to achieve the most accurate gradient removal.

To get the best image under less-than-ideal conditions, you need to subtract the gradients and nothing else, but you can't produce an image that contains only gradients. You can, however, get close enough to carry on with your science or artistic rendition. Currently there are two methods for getting pretty close to producing a faithful image of gradients. The first is to shoot "superflats" during your imaging session. Superflats are flat-field calibration images recorded near the time and area where you captured your target data. For the majority of amateurs, this is impractical, and takes away valuable imaging time. Furthermore, superflats do not take into account changing conditions such as encroaching twilight.

The other method is to create an artificial representation (model) of the gradients in your image. So how can you create an artificial gradient? The most plausible solution is to measure small areas (samples) from strategic locations in the original image and produce a simulation of the gradient. Fortunately, there are tools that make this process much easier than it might seem.

All other conditions being equal, the larger your camera's, telescope's, or lens's field of view, the more obvious the gradients will be, but even images only 1° wide or less can and do show gradients.

PixInsight

Although there are a few programs today that offer point-measured gradient removal, I prefer the tools available in *PixInsight 1.81* from Pleiades Astrophoto (**http://pixinsight.com**). I find that this program offers much more control and produces better results than the others available today. Here's how I achieve my best results.

I usually begin with a calibrated and combined image with any non-overlapping edges cropped off. My first step is to apply an automatic ScreenTransferFunction (STF) by selecting Image > STF AutoStretch from the pulldown menu to increase the image contrast, revealing any gradients in the image.

Once identified, *PixInsight* has two tools that can suppress gradients: AutomaticBackgroundExtractor and DynamicBackgroundExtraction (ABE and DBE for short). ABE, as its name implies, is mostly automatic and doesn't enable you to interact with the image. Launch the ABE module by going to the PROCESS > BackgroundModelization > AutomaticBackgroundExtractor. You can then adjust a few parameters that will launch the sample-generation and background-modeling engines. Set the Target Image Correction to Subtraction and then click the blue square at the bottom-left to produce a background model and corrected image. Unfortunately, this tool doesn't always discriminate between the subject and background, often resulting in inaccurate gradient corrections.

Facing page: Practically everyone shooting deep-sky astrophotos will at some time encounter brightness gradients across an image. Notice the gradient in this photo of the Virgo Cluster, which appears bright at the top-left and dark at the bottom-right. Author Rogelio Bernal Andreo explains how to remove this unwanted signal from your own images using *PixInsight*.

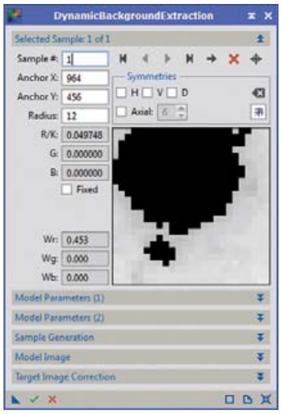
***PixInsight*'s AutomaticBackgroundExtractor (ABE) tool enables users to quickly generate a gradient map of an image and subtract it. Although this works well in some instances, it often indiscriminately maps galaxies and bright stars as brightness gradients that should be suppressed. This gradient map of the sky background was taken from the image on the facing page using the ABE tool. Note its lumpy, uneven appearance.**

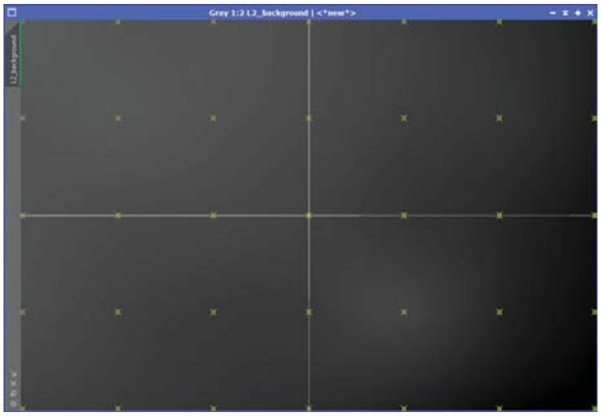
Dynamic Background Extraction

My preferred method uses the DBE tool (PROCESS > BackgroundModelization > DynamicBackgroundExtraction), which I find to be the most flexible and user-friendly gradient removal method available to amateurs today.

The best way to know whether you're removing the gradient and nothing else after applying ABE or DBE on an image is not by looking at the corrected image, but at the background model image that the ABE or DBE tools created and later subtracted.

Regardless of how wonderful your image might look after your first application of ABE or DBE, you should carefully check that the process only removed the gradient signal — nothing more, nothing less. A gradient





Far left: The DynamicBackground-Extraction tool (DBE) allows you to carefully select and evaluate each background sample to ensure the best results. In this example, a bright star was chosen as a background sample, which produced the bright "lump" in the resulting background map to its right. *Near left:* Moving our DBE sample points from the raw image to the first background map shows that the bright "lump" at the bottom right corresponds to a poorly chosen sample near a group of galaxies.

shouldn't have a lumpy texture with bright areas scattered around the image like the background model example seen above. DBE probably chose a sample point on a galaxy or bright star. As a result, the model has removed desired signal, preserved unwanted signal (gradients), or a bit of both. To get the DBE tool to function best, it takes a little finessing of a few settings.

After opening the DBE tool, click within your target image. This will place symmetry guide lines across the picture and link the image to anything you do with the DBE tool. Start by defining a small number of samples per row in the Samples Generation menu. Although the default of 10 sample points is appropriate, I prefer a smaller number. Gradients usually present smooth transitions that are well defined with only a few samples, though severe cases may require more. For an image that's roughly 4,000-by-3,000 pixels and that displays a smooth gradient when the STF AutoStretch is applied, six samples per row seems a good number to start with. Once you've made this change, click the Generate button.

Often the DBE tool may refuse to place samples in certain areas of an image because they're too bright or too dark. The goal is to have the image's entire surface well sampled. One way to make sure DBE places samples in brighter and darker areas is by increasing the Tolerance value to 2 and decreasing the value of Minimum Sample Weight to 0. This tells DBE to accept almost every sample, no matter how bright or dark it is.

Click the Generate button again, to see where DBE places the samples after the changes.

After examining and removing questionable sample points, the DBE tool should produce a smooth and even gradient of the target image, like this.

With new additional sample points generated, make sure they're sampling areas free of stars or other subjects you want to keep in the image, such as faint nebulosity. Take a look at the point sample in the DBE window at the top of the page. Although the star is rejected (the area in black), the sample is poor: many pixels in the sample are rejected, and the pixel edges around the black area that are usually a bit brighter than the real background (darker in the inverse sample image shown by DBE) may affect the reading. It's best to move or remove this sample point altogether by clicking the red X at the top right of the window.

When you're satisfied with the sample placement, make sure that the Target Image Correction is set to Subtraction, and click the execute icon (green check mark). After a few seconds, two new images are created. One is the corrected result, the other a background model.

Again, examine the background model, this time side-by-side with the original image and the location of the samples. I often adjust the STF shadow/midtone/highlight sliders on the background model image to increase the contrast of the model to better display differences in illumination (PROCESS > IntensityTransformations > ScreenTransferFunction).

To illustrate what is going on in my background model, I'll place the samples from my corrected image over the background model image. This is accomplished by dragging DBE's New Instance icon (the blue triangle at bottom left) to the program workspace, canceling the DBE process (red X icon at bottom left), clicking on the background model image, and then double-clicking on the DBE process I dragged onto the workspace.

See that sample over the brighter area in the bottom-right in the image above? That's the sample responsible for that bright lump. This tells me that I should remove that sample. The best practice is to remove samples from bright areas that break a smooth transition, and to add samples in dark areas. Besides adding and removing samples, you can also move them around to more ideal locations to produce the best model of the background sky.

Once you're satisfied with all the sample points, apply the changes to the original image. Make sure to transfer

Although we can never be absolutely sure that every brightness variation in an image is real, removing the gradients in this photo enabled the author to reveal what appears to be faint nebulosity.

the adjustments to the DBE back over to the raw image using the same steps you used to move them to the background map. You can then examine both the corrected image and the new background model based on the adjusted set of samples.

If you're still seeing lumps in the background model, continue adding, removing, or moving samples around and reapply. After a few interactions with DBE, you should end up with a background model that closely resembles the gradients in your target image. At that point, you can apply an STF stretch to the corrected image and inspect it for any additional gradients.

In my example on the left of the Virgo Galaxy Cluster, the resulting background isn't evenly illuminated. But my background model transitions very smoothly across the entire field, so these differences in "background illumination" must not be an artifact introduced by my efforts to remove gradients. This is the extremely faint dust and nebulosity that permeates the Milky Way. Accurately removing gradients enabled me to aggressively stretch the image to reveal it.

If your original data was just a couple of hours of exposure under suburban skies or through subpar conditions, chances are that any existing faint signal wasn't detected, or is buried under several sources of noise. In other words, a poor signal-to-noise ratio makes it impossible to reveal faint objects. In my example, the image is more than 25 hours of luminance under very dark skies. These conditions allowed me to obtain sufficient signal of these extremely faint objects.

It might be daring for an amateur with a small telescope to claim that the uneven illumination reveals faint interstellar dust or nebulosity. And although we can never be 100% certain that every background-intensity variation corresponds to actual objects in our images, with this accurate gradient removal technique, we can be very confident that most leftover variations are indeed data-driven, and not processing artifacts. ✦

Rogelio Bernal Andreo *often images elusive nebulosity from the darkest locations in the southwest United States.*

You can use the DBE tool on any deep-sky image with adequate exposure. The author captured this mosaic of M78 and LBN 1622 using a Takahashi FSQ-106EDX and SBIG STL-11000M CCD camera and corrected it with his technique.

A Short & Sweet 6-Inch RFT

This ultra-fast Dobsonian is purpose-built for stunning wide-field views.

MANY OF THE BEST telescope makers are also very active observers. For them, designing and building a new scope is a means to an end. They push the boundaries of what is thought feasible, and innovate when current solutions no longer suffice. Oregon ATM Mel Bartels clearly falls into this camp, and his startlingly short 6-inch f/2.8 Newtonian is proof.

"My initial interest was to build the largest-aperture, no-ladder telescope possible — a goal that I am still working toward," said Mel. "I decided to experiment with smaller apertures to find out how much I'd like the views produced by an f/3 or faster mirror, and to try my hand at parabolizing such a fast mirror."

MEL BARTELS

Oregon ATM Mel Bartels displays his ultra-fast 6-inch f/2.8 rich-field telescope. Used in conjunction with a 21-mm Tele Vue Ethos eyepiece, the scope delivers a binocular-sized field of view for breathtaking deep-sky vistas.

More than simply a test bed, Mel's 6-inch f/2.8 is a nifty rich-field telescope (RFT) — an instrument that delivers the maximum amount of starlight for a given aperture. For optimum results, the telescope and eyepiece must be considered together as part of a single optical train. That means selecting an eyepiece that simultaneously gives the widest field of view at the highest magnification while matching the maximum size of your eye's fully dark-adapted pupil.

Mel started with the eyepiece (a 21-mm Tele Vue Ethos) and determined that an f/2.8 mirror used with a Tele Vue Paracorr Type-2 coma corrector (which increases the primary's focal length and f/ratio by a factor of 1.15×) would be ideal for his eye's 6.5-mm pupil. "Having made RFTs in the past, I was quick to realize the advantage of a modern eyepiece with a 100° apparent field coupled with a super-fast primary," says Mel. A subtle, but important consequence of these new eyepieces is that they permit a wider true field of view with a given aperture than ever before. Equipped with the 21-mm Ethos, Mel's 6-inch provides a true field that's 4.9° wide at a magnification of 23×. By comparison, typical astronomy binoculars deliver that same celestial real estate, but at less than half the magnification and with anemic 2-inch objective lenses.

It wasn't long ago that a mirror faster than f/4 would cause even experienced ATMs to tremble with apprehension. Now, f/3 mirrors are the new f/4. Such fast mirrors are challenging, and ones faster than f/3 are largely uncharted territory for amateurs. So what was it like to make an f/2.8 mirror? "I was very worried about my ability to generate a smooth curve at the steep deviations from spherical that such a paraboloid calls for," he recalls. The key to success was an oversized pitch lap — one with a diameter slightly greater than that of the mirror. This enabled Mel to figure the mirror without introducing the kind of surface roughness often produced with the sub-diameter tools typically used to figure fast mirrors.

But for a truly fine optic, the mirror must be smooth *and* accurately figured. "The figuring was certainly touchy — polishing for only seconds with diluted, high-quality cerium oxide was enough to cause subtle changes," Mel reports. But in most respects, the f/2.8 was similar to making an f/3, which Mel had done previously (*S&T:* Jan.

MEL BARTELS

At first glance the scope looks like a conventional but stubby Dobsonian. Note that the side bearings are offset to ensure the scope will remain balanced with a heavy eyepiece, even when aimed vertically.

2012, p. 62). Crucial to the process was star testing throughout the figuring stage. Although terribly time consuming, this enabled him to monitor progress with a great deal of accuracy and sensitivity, while also evaluating the entire optical train as a complete system.

But the effort paid off. "I cannot get over how beautiful the ultra-wide-angle views are — it's like pulling back the curtains and going from a peephole to seeing a grand vista," says Mel. "Every object I've seen before is worth viewing again and seeing in a new light."

If this whets your appetite for a superfast telescope of your own, there's only one way to get one: build it yourself. Is that feasible? Probably not as a first-time project, but if you've already made a couple mirrors with normal f/ratios, a fast optic such as this is within reach. Skill and patience are prerequisites, and as Mel notes, "I don't see how one can escape using the star test, since the figure is so touchy — and it takes hours on a night of good seeing for a single critical test."

Readers wishing to learn more about Mel's 6-inch refractor can visit: **http://tinyurl.com/mkwjcyz.** ✦

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*Contributing editor **Gary Seronik** is an experienced telescope maker whose fastest mirror to date is a pedestrian f/4. He can be contacted via his website, **www.garyseronik.com**.*

▲ **H-ALPHA EYEPIECE** DayStar Filters introduces the Quark ($995), a compact solar hydrogen-alpha filter for fast refractors. This electronically controlled, temperature-regulated etalon features a 21-mm clear aperture with integrated telecentric Barlow lens and 12-mm blocking filter. Users of fast 80-mm refractors can simply place the unit in their diagonal, add a low-power 1¼-inch eyepiece, and start enjoying views of the Sun's dynamic chromosphere. Available in chromosphere and prominence versions, the Quark unit fits in both 1¼- and 2-inch focusers, and requires no additional filters when used with 80-mm or smaller refractors with focal ratios of f/4 to f/9 on non-tracking mounts. Each purchase comes with a plastic case, end caps, and an AC power supply with international plug adapters. An optional thread-on UV/IR blocking filter to mount in front of your diagonal or full-aperture energy-rejection filter is recommended for use on tracking telescopes of up to 6-inch aperture. Not recommended for oil-spaced objectives or off-axis applications. See DayStar's website for additional details and accessories.

DayStar Filters
149 NW OO Hwy., Warrensburg, MO; 64093
866-680-6563; www.daystarfilters.com

▶ **OPTICS CLEANER** Photonic Cleaning Technologies introduces First Contact Polymer Solutions ($110), which cleans your optical surfaces without leaving residue. Simply spray, brush, or pour the polymer solution on your telescope mirror or lens. Once dry, First Contact Polymer becomes a strong, flexible film that you can then peel off to remove any fingerprints, dust, pollen, or other contaminants without damaging delicate optical coatings. The Red First Contact Starter Kit includes a 15-milliliter bottle with applicator brush, one 29-ml dilution spray, two 29-ml refill bottles, and 30 peel tabs for removing the dried polymer film. See the manufacturer's website for larger quantities and other options.

Photonic Cleaning Technologies
P.O. Box 435, Platteville, WI 53818;
608-467-5396; www.photoniccleaning.com

THE SKY APP Software Bisque announces its long-anticipated expansion into the app market with the release of *TheSky Mobile* ($14.99) for the iPhone and *TheSky HD* for the iPad ($29.99). Both include an extensive feature set tailored to the intermediate and advanced amateur. *TheSky* for iOS integrates popular features from the desktop editions, including field-of-view indicators for many telescope, eyepiece, and camera combinations; large astronomical databases (including satellites and minor planets); integrated photos of popular astronomical objects; and much more. *TheSky's* Wi-Fi telescope control (a Wi-Fi-to-serial adapter is required and sold separately) offers a powerful and elegant alternative to your Go To telescope's hand paddle, allowing you to control their telescopes directly with your iPhone or iPad device. *TheSky HD* for the iPad also integrates with DC-3 Dreams *ACP Observatory Control Software*, enabling users to plan, submit to ACP, and execute their observing session without having to exit *TheSky*. Additional catalog plug-ins can be downloaded from the manufacturers website free of charge.

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Available at the iTunes App Store
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◂ **NAVI NEBULOSITY**

Jesús Nieto

The 2nd-magnitude star Navi (γ Cassiopeiae) at top-right illuminates emission and reflection nebula IC 59 (left) and 63 (bottom).

Details: *Astro-Physics 130EDFGT refractor with QSI 683ws CCD camera. Total exposure was 20½ hours through Astrodon Hα and blue filters.*

▾ **LUCKY CATCH**

Jay Mason

A bright meteor disintegrates above the Joshua Tree National Park in California on the night of the Camelopardalid meteor shower last May 24th.

Details: *Nikon D800 DSLR camera with 14-to-24-mm zoom lens. Total exposure was 20 seconds at ISO 2500.*

▲ **PANSTARRS MEETS NGC 3614**

Mike Keith

Comet PanSTARRS C/2012 K1 was sporting two faint tails as it passed by the distant spiral galaxy NGC 3614 in Ursa Major on the evening of May 24th.

Details: *Astro-Physics 140EDF27 refractor with Starlight Xpress Trius H694 CCD camera. Total exposure was 2 hours through color filters.*

◄ **A SEA OF STARS**

Fred Herrmann

Thousands of old red stars swarm within globular cluster NGC 3201 in the southern constellation Vela.

Details: *PlaneWave Instruments CDK20 Corrected Dall-Kirkham telescope with FLI PL09000 CCD camera. Total exposure was 12 minutes through color filters.*

▶ **DRAMATIC ECLIPSE**

David Milone

Both the illuminated and eclipsed halves of the Moon of April 15th appear in full detail thanks in part to high-dynamic-range processing techniques.

Details: *120-mm f/7.5 ED refractor with Canon EOS 1000D DSLR camera. Combination of 2-second and 1⁄250-second exposures.*

▼ **LIGHTHOUSE ECLIPSE**

Chris Cook

Last spring's eclipsed Moon appears just above Spica, while Mars shines at its brightest (shortly after it reached opposition) farther to its right as seen with the famous Chatham Lighthouse on Cape Cod, Massachusetts.

Details: *Canon EOS 5D DSLR camera with 24-to-70-mm zoom lens. Total exposure was 5 seconds at ISO 1250.*

MEXICO BOW-SHOCK

André van der Hoeven

One of the most richly detailed areas of NGC 7000, the North America Nebula, is the "Mexico" region. It's riddled with delicate strands of dust silhouetted against bright emission nebulosity.

Details: *TEC APO 140 refractor with QSI 583 CCD camera. Total exposure was 11 hours through Astrodon color and narrowband filters.* ✦

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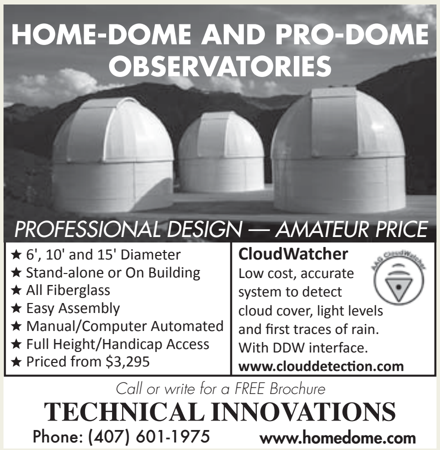

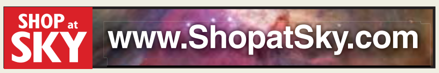

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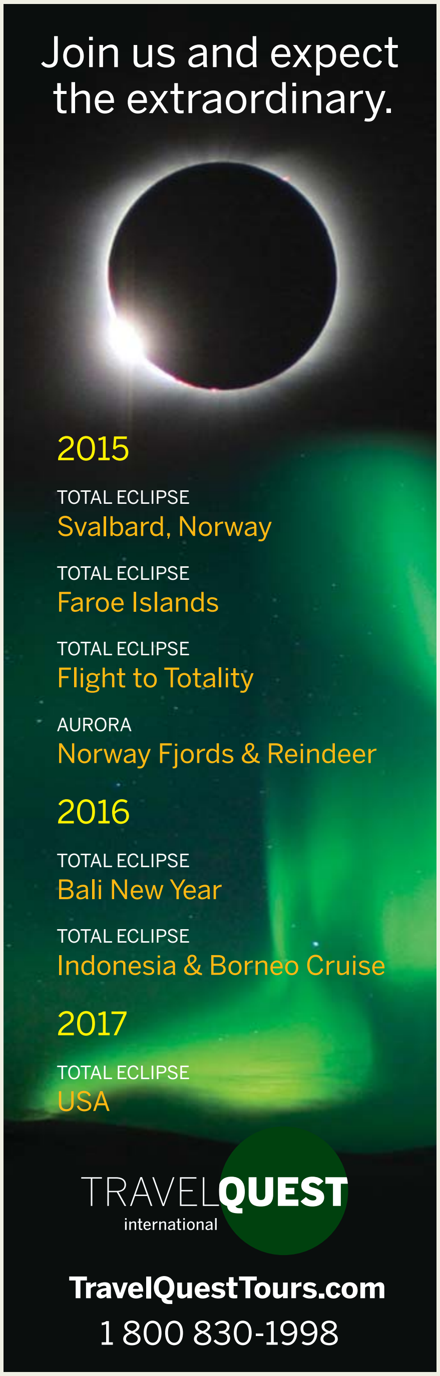

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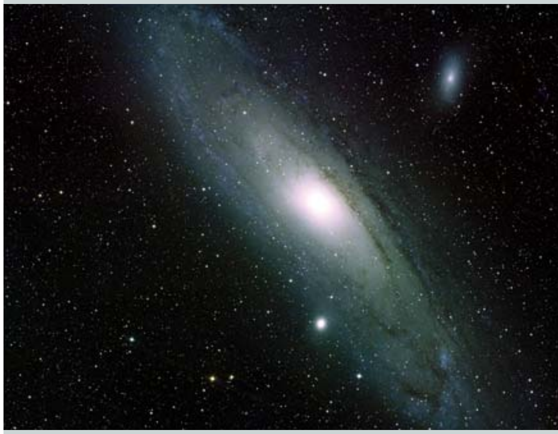

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CubeSats to the Planets

Miniaturized spacecraft might soon be exploring the solar system.


UNIVERSITY OF MICHIGAN

It's no secret that CubeSats are changing the face of space exploration in a dramatically affordable way (*S&T:* Nov. 2013, p. 64). But new technologies could turn slightly larger versions of today's CubeSat designs into budget-priced interplanetary probes by the end of the decade.

The first CubeSats had no active propulsion. But numerous systems are maturing that will enable them to perform a wide range of maneuvers. Aerojet Rocketdyne is developing miniaturized chemical thrusters. BUSEK Space Propulsion and Systems is pursuing pulsed plasma and ion thrusters, producing very low thrust at very high efficiencies. One of the most promising avenues is solar sailing, which uses the pressure exerted by sunlight on thin, reflective membranes. Since the Japanese IKAROS mission demonstrated the feasibility of interplanetary solar sailing in 2010, NASA has issued a requirement that CubeSat solar sails measure no more than a hundred square meters. The sails must be stowed and deployed from tight volumes, which poses the central challenge facing these systems.

A conventional rocket could deliver an interplanetary CubeSat into Earth orbit as a secondary payload. After a solar sail is deployed, each successive orbit could boost the CubeSat into an ever-widening spiral trajectory that would ultimately achieve escape velocity. A 1997 publication outlined a series of pathways through the inner solar system called the Interplanetary Transfer Network (ITN). These trajectories optimize the gravity-assist technique used so successfully since NASA's Voyager missions to vastly reduce the acceleration needed to reach another celestial body. ITN missions would take longer and follow a convoluted path, but, for an uncrewed vehicle with limited propulsion, they would be ideal.

Interplanetary CubeSats would have to transmit large data volumes over hundreds of millions of miles. In the wake of NASA's recent LADEE mission, which demonstrated the feasibility of laser transmission from lunar distances at data rates high enough to stream movies, NASA is working with the Aerospace Corporation to test a CubeSat version of a similar system by early 2015. Instead of using radio, interplanetary CubeSats will communicate by transmitting optical laser signals to large telescopes.

CubeSats will suffer radiation damage to electronics and subsystems. These concerns are magnified for CubeSats spending months or years in interplanetary space, where they're not protected by Earth's magnetic field. As devices are miniaturized, they become even more vulnerable. Researchers are developing techniques to harden these systems by providing multiple data paths and processors.

Interplanetary CubeSats will never replace larger planetary probes such as the Mars rovers. After all, some missions will require large telescopes or bigger probes that carry more instrumentation. But when only one or two instruments are required that can be sufficiently miniaturized, the range of potential missions is wide. JPL researchers are planning several interplanetary CubeSat missions: an asteroid mineral prospector, a space-weather-monitoring platform, and even a sample return from one of Mars's moons. At about $30 million each, these missions could be flown for a fraction of the cost of conventional planetary probes. Since the first Interplanetary CubeSat Workshop in 2012, the gathering has become an annual event that offers a unique opportunity for collaboration among the growing list of players in this promising new field. ✦

***Paul Contursi** is a space advocate, consultant, and entrepreneur focusing on CubeSat launch services.*


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